PB82-110289

Airborne Radioactive Emission Control Technology
Volume III

Dames and Moore
White Plains, NY

Prepared for

Office of Radiation Programs
Washington, DC

Mar 80

U.S. Department of Commerce
National Technical Information Service
NTIS

BIBLIOGRAPHIC DATA SHEET

1. Report No. ORP Contract Report 81-5C

2.

3. Recipient's Accession No. PB82 110289

4. Title and Subtitle

Airborne Radioactive Emission Control Technology
Vol . 3

5. Report Date March 1980

6. U272024

7. Author(s)

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8. Performing Organization Rept. No.

9. Performing Organization Name and Address

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10. Project/Task/Work Unit No.

11. Contract/Grant No. 68-01-4992

12. Sponsoring Organization Name and Address

Office of Radiation Programs
U.S. Environmental Protection Agency
401 M. St. SW
Washington, D.C. 20460

13. Type of Report & Period Covered

14.

15. Supplementary Notes

16. Abstracts

This report reviews the current and future control technology for airborne emissions from a wide variety of industries/facilities, including uranium mining and milling, other nuclear fuel cycle facilities, other NRC-licensed and DOE facilities, fossil fuel facilities, selected metal and non-metal extraction industries, and others. Where specific radioactivity control technology is lacking, a description of any existing control technology is given. Future control technology is assessed in terms of improvements to equipment performance and process alterations. A catalogue of investigated research on advanced control technologies is presented.

17. Key Words and Document Analysis. 17a. Descriptors

Airborne radioactivity source terms
control technology effectiveness
control technology costs
effluent system designs
research and development

17b. Identifiers/Open-Ended Terms

17c. COSATI Field/Group

18. Availability Statement

Release Unlimited

19. Security Class (This Report) UNCLASSIFIED

20. Security Class (This Page UNCLASSIFIED

21. No. of Pages

22. Price

PB82-110289

ORP Contract
Report 81-5C

AIRBORNE RADIOACTIVE EMISSION CONTROL TECHNOLOGY

VOLUME III

DAMES & MOORE
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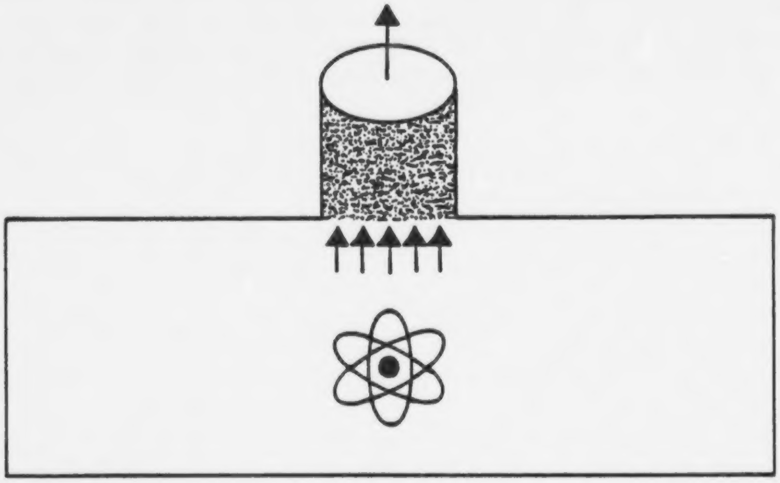

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U.S. ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

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SPRINGFIELD, VA 22161

NOTICE

This report was prepared by Dames & Moore for the United States Environmental Protection Agency's Office of Radiation Programs (ORP) under Contract No. 68-01-4992. ORP has reviewed it, and the contractor has responded to our comments. We are publishing this report because of its useful information. We have not verified all of the results ourselves, however; nor have we applied our own editorial standards to the text. ORP does not necessarily publish all of the contractor reports it receives.

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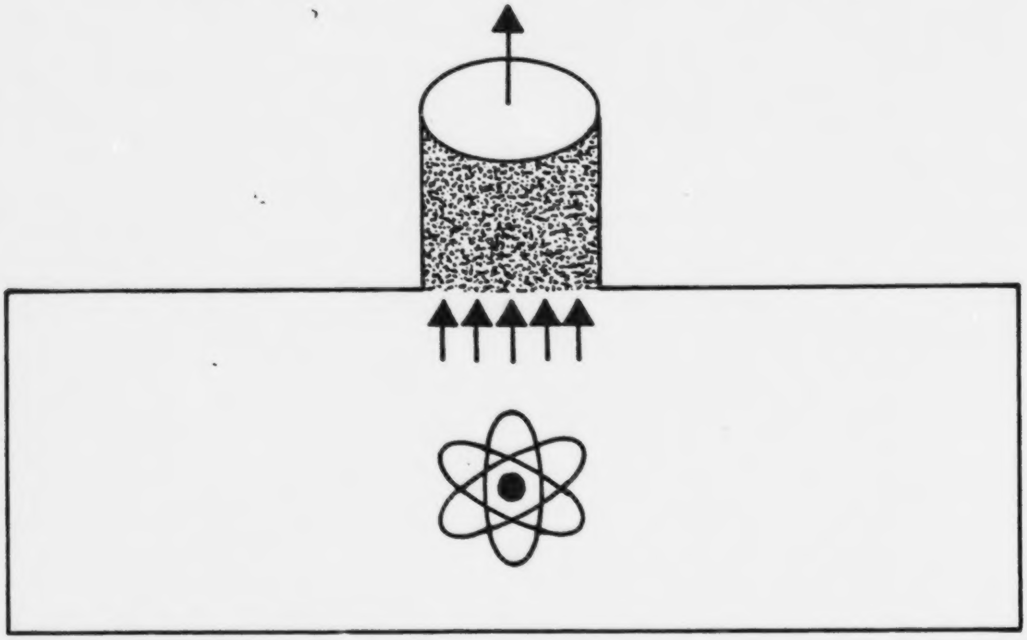

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CHAPTER III

Introduction

The previous chapter considered the existing technologies for control of airborne radionuclide emissions in terms of facilities that may handle material containing radioactivity. This chapter considers the existing airborne emission control technologies in terms of specific radioactive isotopes that can be found in airborne effluents.

The discussion in this chapter will be limited to the airborne emission control technologies utilized at "nuclear" facilities, i.e., facilities that handle material containing radioactivity, release radionuclides in their airborne effluents, and are required to meet radiological airborne emission regulations and/or criteria.(1-1,1-2) The "non-nuclear" facilities may also process material containing radionuclides. However, their airborne emission control technologies are not designed to meet any specific radiological airborne emission regulation and/or criterion, and consequently, these technologies may control radionuclide emissions incidentally and not as their primary function. For this reason it is extremely difficult to correlate information on the airborne emission control technologies, such as efficiency and costs, at non-nuclear facilities with the radioactive contents of their effluents. Therefore, non-nuclear facilities have been excluded from the discussion in this chapter.

A general background section applicable to the consideration and implementation of a specific airborne emission control technology for a specific radionuclide is presented below, followed by the discussion of the airborne emission control technologies utilized for two major categories of radionuclides: particulates and gases.

Background

As previously discussed in Chapter II, for a given facility, the applicability of an airborne emission control technology is determined after an evaluation of several factors among which are the potential for airborne contamination within the facility, the relative radiotoxicities of the specific isotopes being handled, and the quantity of radioactive material being handled.(1-2)

The potential for airborne releases is governed by the form and the usage (or process) of the specific material being handled. For example, in the case of a by-product material licensee utilizing a nickel-63 (activation product) foil for an electron capture detector on a gas chromatograph, or a licensee employing a strontium-90 sealed source for instrument calibration, the potential for airborne contamination is negligible. Conversely, in the case of a reprocessing plant where kilocurie quantities of radioactive material are remotely handled in a mechanical processing cell where fuel rods are chopped up, substantial measures must be taken to prevent release of airborne contamination.

The relative radiotoxicity (Chapter II, Table 3-1) is also an important consideration. Radiotoxicity and its impact on nuclear air cleaning considerations have been discussed in detail in Chapter II, Section 3. One of the major factors that determine the specific delineation of pressure zones is the relative radiotoxicity of the material to be handled in each zone. In general, the higher the relative radiotoxicity of the radionuclide in question is, the more stringent the air cleaning technology employed should be.

The third major factor is the quantity of material being handled. For example, by-product materials are handled from the microcurie to the kilocurie levels. The quantities handled in university laboratory experiments or small scale industrial process tracer studies usually do not require an airborne emission control technology. Conversely, if large quantities of radioactive material are being handled at the facility, even if the radiotoxicity of the material in question is very low, then an airborne emission control technology is indicated.

After the requirement of an airborne emission control technology has been estaplished, then the specific control technology applied to the airborne effluent of a facility is selected after an evaluation of the cost effectiveness has been performed for those control technologies that enable the facility to conform with the applicable criteria and regulations.

Several factors contribute to the evaluation of the cost effectiveness of a given control technology from among those that satisfy the applicable criteria and regulations. Among these factors are the throughput volume of the effluent stream to be controlled, the chemical composition and constituents of the effluent stream, and the specific facility function and design.

For example: the throughput of the effluent stream may indicate that scrubbers may be more cost effective than electrostatic precipitators (see Chapter II, Section 5); the constituents of the effluent stream, e.g., hydrogen fluoride (HF), may preclude the use of certain type of control technology, e.g., HEPA filters (see Chapter II - Section 3); and if the effluent stream to be controlled originates from a few glove boxes or chemical hoods, then it would not be cost effective to utilize a control technology such as venturi scrubbers. (1-2)

Particulates

Many different types of technologies are utilized to control airborne emission of particulates. Among these are scrubbers, electrostatic precipitators (ESP), dry dust collectors, High Efficiency Particulate Air (HEPA) filters, and sand filters. These technologies, which are more fully discussed in Chapter II, are summarized below.

Scrubbers are utilized to remove particulates from gaseous streams through the physical and chemical interaction between the particulates and a scrubbing medium such as water. Depending on the scrubbing medium, scrubbers can also remove gaseous radioactive effluents. There are many different kinds of scrubbers (with the associated vendor mass efficiencies) such as baffle scrubbers (about 93%), wet impingment scrubbers (about 98%) and venturi scrubbers (about 99+%). The efficiencies depend on many factors such as the pressure drop across the device, particulate load, system design, and effluent chemical composition. Scrubbers require about three times as much energy to operate as the corresponding dry dust collectors, and usually discharge liquid effluents whose magnitude depends on the operating conditions.

The process of electrostatic precipitation involves the removal of dust or liquid aerosol from a gas stream by imparting an electric charge to the contaminant and then passing the stream through an electric field. ESPs are used for varying purposes such as recovering precious metals, or removing fly ash from coal fired boiler off-gas. The principal uses of ESPs today are in facilities where large collection efficiencies for small particles are required from large volumes of effluents. The efficiencies generally range from 98% to 99+% under suitable conditions. Operating costs and energy use of ESPs are comparable to corresponding scrubbers, and they usually discharge solid effluents whose magnitude depends on the operating conditions.

Dry dust collectors include vacuum cleaner bags, cyclones, fabric filters (some of which are also called baghouse filters and jet bag filters), fiberglass filters, metal filters, and porous carbon filters. These technologies are usually utilized on cool, dry effluents with suitable chemical compositions. Some of the efficiencies given by the vendors are: 98% for particles greater than 0.7 um diameter for metal filters with 10 um pore size; 99.9% or higher depending on the operating conditions for particles greater than 1.0 um diameter for reverse-jet bag filters; and 99.9995% for UF_6 dusts for porous carbon filters. Dry dust collectors are usually utilized as pre-filters in HEPA systems, although they may also be utilized independently. The energy requirements of dry dust collectors are comparatively less than for scrubbers or ESPs, but their maintenance costs are usually higher. Dry dust collectors usually discharge solid effluents and/or filters.

The HEPA filters are utilized extensively in the nuclear fuel cycle and other nuclear facilities as the last particulate removal technology in a control system prior to airborne release. Frequently, the gaseous stream to be controlled is passed through other control technologies to obtain optimal operating conditions for HEPA filters, e.g., pre-filters for removal of large size particles to prolong HEPA life, or devices to remove hydrogen fluoride since it severely affects HEPA performance. Efficiencies depend on many factors including pressure drop, operating conditions, and installation conditions. The most frequently quoted vendor efficiency for a HEPA filter is 99.97% for particles greater than 0.3 um diameter, if the filter system has been installed properly (see Appendix II.A). Energy use of HEPA filters is comparable to dry dust collectors, but maintenance costs are considerably higher. Under optimal design conditions, the only residuals of HEPA filters are spent filters.

Sand filters are usually fixed bed filters constructed of graded layers of aggregate and sand with particle sizes down to 50 mesh.

They have good resistance to variations in operating conditions but have the disadvantages of higher cost, higher pressure drop, and lower particulate efficiencies (about 99%) when compared to HEPA filters. Tests have demonstrated that a 30-inch deep sand filter bed is equivalent to a single HEPA filter for particle sizes remaining airborne after passing through two stages of HEPA filters. They are mainly utilized at National Laboratories (see Chapter II, Section 4).

The existing airborne emission control technologies for particulate radionuclides will be discussed below in three major categories; uranium and thorium and their particulate daughters, transuranic radionuclides, and other particulates including fission and activation products.

Uranium, Thorium, and Their Particulate Daughters

The uranium series (both ^{238}U and ^{235}U as the progenitor) and the thorium series (^{232}Th as the progenitor) occur in nature and constitute a significant part of the background radiation. These series are summarized in Tables 1-1 through 1-3.

In nature, the daughter products of these chains occur together with the progenitor of the chain usually in quantities approaching "secular equilibrium", i.e, the activity of each daughter is equal to the activity of the progenitor. However, during the mining and milling of the ore, most of the daughter products are separated from the progenitor. If the daughter products are separated during the process, the periods of concern are not long enough for the long-lived daughters (e.g., ^{230}Th and ^{226}Ra) to reach secular equilibrium with the progenitor. However, the short-lived daughters can usually be assumed to be in secular equilibrium with the first long lived parent. For example (see Tables 1-1 and 1-2): for the ^{238}U series

TABLE 1-1

Uranium-238 Decay Series Radionuclides*

Symbol/Element	Isotope	Half-Life	Type of Disintegration** and Particle Energy	Daughter
92 (U) Uranium	238	4.5E9 years***	a : 4.20 MeV	Th-234
90 (Th) Thorium	234	24.1 days	b : 0.19 MeV	Pa-234
91 (Pa) Protoactinium	234	1.18 minutes	b : 2.32 MeV	U -234
		6.7 hours	b : 1.13 MeV	U -234
92 (U) Uranium	234	2.5E5 years	a : 4.768 MeV	Th-230
90 (Th) Thorium	230	8.0E4 years	a : 4.68 MeV	Ra-226
88 (Ra) Radium	226	1620 years	a : 4.777 MeV	Rn-222
86 (Rn) Radon	222	3.82 days	a : 5.486 MeV	Po-218
84 (Po) Polonium	218	3.05 minutes	a : 5.998 MeV	Pb-214
			b : ?	At-218
82 (Pb) Lead	214	26.8 minutes	b : 0.7 MeV	Bi-214
85 (At) Astatine	218	1.5-2 seconds	a : 6.63 MeV	Bi-214
83 (Bi) Bismuth	214	19.7 minutes	a : 5.51 MeV	Tl-210
			b : 3.17 MeV	Po-214
84 (Po) Polonium	214	1.64E-4 seconds	a : 7.683 MeV	Pb-210
81 (Tl) Thallium	210	1.32 minutes	b : 1.9 MeV	Pb-210
82 (Pb) Lead	210	19.4 years	b : 17 KeV	Bi-210
			a : 3.72 MeV	Hg-206
83 (Bi) Bismuth	210	5.0 days	b : 1.155 MeV	Po-210
84 (Po) Polonium	210	138.3 days	a : 5.3 MeV	Pb-206
80 (Hg) Mercury	206	8.1 minutes	b : 1.3 MeV	Tl-206
81 (Tl) Thallium	206	4.2 minutes	b : 1.51 MeV	Pb-206
82 (Pb) Lead	206	Stable		

---

* Source : The data from Ref 1-3 supplemented by data from Ref 1-4.

** (a) denotes alpha-particle, (b) denotes beta-particle.

*** Exponential notation, i.e., 4.5E9 = 4.5x10^9.

TABLE 1-2

Uranium-235 Decay Series Radionuclides*

Symbol/Element	Isotope	Half-Life	Type of Disintegration** and Particle Energy	Daughter
92 (U) Uranium	235	7.1E8 years***	a : 4.559 MeV	Th-231
90 (Th) Thorium	231	25.6 hours	b : 0.30 MeV	Pa-231
91 (Pa) Protoactinium	231	3.43E4 years	a : 2.32 MeV	Ac-227
89 (Ac) Actinium	227	21.6 years	a : 4.94 MeV	Fr-223
			b : 46 KeV	Th-227
90 (Th) Thorium	227	18.17 minutes	a : 6.03 MeV	Ra-223
87 (Fr)	223	22 minutes	a : 5.34 MeV	At-219
			b : 1.2 MeV	Ra-223
88 (Ra) Radium	223	11.68 days	a : 5.864 MeV	Rn-219
85 (At) Astatine	219	0.9 minutes	a : 6.27 MeV	Bi-215
			b : ?	Rn-219
86 (Rn) Radon	219	3.92 seconds	a : 6.81 MeV	Po-215
83 (Bi) Bismuth	215	8 minutes	b : ?	Po-215
84 (Po) Polonium	215	1.83E-3 seconds	a : 7.37 MeV	Pb-211
			b : ?	At-215
82 (Pb) Lead	211	36.1 minutes	b : 1.39 MeV	Bi-211
85 (At) Astatine	215	1.0E-4 seconds	a : 8.0 MeV	Bi-211
83 (Bi) Bismuth	211	2.11 minutes	a : 6.617 MeV	Tl-207
			b : ?	Po-211
84 (Po) Polonium	211	0.52 seconds	a : 7.442 MeV	Pb-207
81 (Tl) Thallium	207	4.79 minutes	b : 1.44 MeV	Pb-207
82 (Pb) Lead	207	Stable		

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* Source : The data from Ref 1-3 supplemented by data from Ref 1-4.

** (a) denotes alpha-particle, (b) denotes beta-particle.

*** Exponential notation, i.e., 7.1E8 = 7.1×10^{8}.

TABLE 1-3

Thorium-232 Decay Series Radionuclides*

Symbol/Element	Isotope	Half-Life	Type of Disintegration** and Particle Energy	Daughter
90 (Th) Thorium	232	1.39E10 years	a : 4.007 MeV	Ra-228
88 (Ra) Radium	228	6.7 years	b : 0.04 MeV	Ac-228
89 (Ac) Actinium	228	6.13 hours	b : 2.18 MeV	Th-228
90 (Th) Thorium	228	1.91 years	a : 5.423 MeV	Ra-224
88 (Ra) Radium	224	3.64 days	a : 5.681 MeV	Rn-220
86 (Rn) Radon	220	51.5 seconds	a : 6.280 MeV	Po-215
84 (Po) Polonium	216	0.16 seconds	a : 6.774 MeV	Pb-212
			b : ?	At-216
82 (Pb) Lead	212	10.6 hours	b : 0.58 MeV	Bi-212
85 (At) Astatine	216	3.0E-4 seconds	a : 7.79 MeV	Bi-212
83 (Bi) Bismuth	212	60.5 minutes	a : 6.086 MeV	Tl-208
			b : 2.25 MeV	Po-212
84 (Po) Polonium	212	3.0E-9 seconds	a : 8.78 MeV	Pb-208
81 (Tl) Thallium	208	3.10 minutes	b : 1.79 MeV	Pb-208
82 (Pb) Lead	208	Stable		

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* Source : The data from Ref 1-3 supplemented by data from Ref 1-4.

** (a) denotes alpha-particle, (b) denotes beta-particle.

*** Exponential notation, i.e., 1.39E10 = 1.39×10^{10}.

the activities of ^{234}Th and ^{234}Pa are usually taken as equal to the activity of ^{238}U, and the activities of all the daughters between ^{226}Ra and ^{210}Pb are taken as equal to the activity of ^{226}Ra; and for the ^{235}U series, activities of all the daughters of ^{227}Ac are taken equal to the activity of ^{227}Ac. This factor may be significant in the selection of an airborne emission control technology for the particulates in the uranium and thorium series.

Specific information on the airborne emission control technologies utilized for ^{232}Th and its particulate daughters could not be obtained, however, it can be assumed that these control technologies are similar to those utilized for uranium and its daughters. Thorium-232 and daughters are omitted from the discussion below.

Material containing ^{238}U and/or ^{235}U and their daughters are handled by all the facilities in the nuclear fuel cycle, and most of the other nuclear facilities, e.g., facilities that hold a "source material" license. However, the airborne emission control technologies which are utilized at the front end of the nuclear fuel cycle (up to and including fuel fabrication) are more representative of the technologies utilized to control uranium. One of the reasons for this is that there is more potential for airborne mobilization of uranium particulates at the front end of the nuclear fuel cycle. At other parts of the cycle uranium exists primarily in liquid and/or solid form. Another reason is the low specific activity of ^{235}U and ^{238}U which implies that at the front end of the fuel cycle, even at secular equilibrium, the airborne uranium particulates would be present in mass amounts much larger than those of its daughters, and control technologies would primarily result in the reduction of the radionuclide present in much larger quantities. Still another reason is the low radiotoxicity of ^{235}U and ^{238}U which implies that at parts other than the front end of the fuel cycle, the control technologies used would be for the control of other, and more toxic, radionuclides such as fission and activation products.

The airborne emission control technologies at the front end of the fuel cycle are summarized below. Data on the technologies, such as efficiencies, capital installation and annual operating costs, residuals, energy use, and effluents are given where available.

There exists no emission control technologies currently used to reduce airborne particulate emissions from underground uranium mines. Open-pit uranium mines routinely use a water-spray system to limit particulate emissions from the mine. The specific effects of this technology on airborne particulate emissions cannot be accurately quantified.

Two types of particulate control technologies used to reduce airborne particulate emissions from operational mills (excluding tailings disposal areas) are baghouse collectors and wet-venturi scrubbers.(1-5, 1-6) Available data indicates that emission rates for uranium (and presumably daughters) from the various discharge points within a mill are on the order of 10^{-5} to 10^{-4} mCi per year per ton of ore processed. No data could be obtained on the chemical characteristics of the discharges. However, it can be assumed that the discharges from the crushing operations would probably be as oxides or silicates (1-7); the discharges from the yellowcake facility or the packaging/drying areas would vary as a function of the degree to which the final product was calcined, but the most probable form would be that of an oxide.

Data on capital and operational costs associated with the control technologies used could not be obtained directly from the mill operators. As a result, cost data were developed, where possible, using secondary sources such as manufacturer's estimates and are given in Chapter II.(1-6).

Physical and chemical stabilization are utilized to reduce particulate emissions from tailings disposal areas. The effect of these measures in reducing fugitive dust emissions is estimated to range between 85-100%.(1-8) Current regulatory guidelines for operational uranium mills require that, after the operations have ceased, the dust emissions from uranium tailings disposal areas to the unrestricted areas be eliminated. Several techniques of stabilization have been identified and are currently being investigated by mill operators.

The particulate control technologies used by UF_6 conversion facilities vary depending on whether the "dry" or the "wet" process is utilized.(1-9, 1-10) Baghouse collectors, cyclones, and porous carbon and metal filters are used for dry processes, and baghouse collectors, cold traps, and scrubbers are used in the wet processes. The airborne effluents contain mostly UF_4, UF_6, and UO_2F_2. Information on the daughter products could not be obtained.

The particulate control technologies utilized in gaseous diffusion facilities are alumina traps (a filter/adsorption medium), potassium hydroxide (KOH) scrubbers, and filter systems including HEPA filters. Data on the chemical form of the discharge could not be obtained.

The predominant radioactive particulate control technology used by fuel fabrication facilities is HEPA filtration.(1-11, 1-12) Pre-filters and/or wet scrubbers are used in addition to HEPA filters on selected portions of the waste stream.

Transuranic Particulates

Transuranics are predominantly man-made isotopes of the elements with atomic numbers greater than that of uranium (atomic number = 92). Transuranics include isotopes of neptunium (Np), plutonium (Pu), americium (Am), curium (Cm), berkelevium (Bk), californium (Cf), einsteinium (Es), lawrencium (Lr), and kurchatovium (Ku) which are the elements with atomic numbers 93 through 104, respectively. For discussion, only the transuranics with half-lives sufficiently long to exist in an airborne effluent are considered. Long-lived transuranic isotopes are listed in Table 1-4. Other isotopes are either too short-lived or of inconsequential mass to be of concern.

The majority of transuranic isotopes exhibit a relatively high radiotoxicity, and consequently, handling of transuranics requires relatively stringent control measures. These control measures encompass a fairly wide range of conditions depending on the amount of transuranics handled and the form they are in. For example, sealed neutron sources such as ^{241}Am or ^{252}Cf do not require an airborne emission control technology, whereas reprocessing plants and weapons associated facilities where kilogram quantities of transuranics are processed require substantial control technologies.

At a facility dealing with microgram to milligram quantities, a glove box set-up, with pressure zonation, fitted with in-place efficiency testable HEPA filtration on both the inflow and outflow ducts are utilized. The circulation system for the glove box room, also fitted with in-place efficiency testable HEPA filters, is independent of the ventilation system of the glove box. An exemplary facility for transuranic control technologies is the Plutonium Facility at LASL (see Chapter II Section 4).

Facilities dealing with kilogram quantities of transuranic materials such as would be the case at a reprocessing plant (1-13, 1-14, 1-15) or a weapons testing facility, a hot cell (a remotely operated processing room equipped with shielding and manipulators) is used at the location of transuranic handling (along with a large inventory of fission and activation products). Pressure zonation and multistage in-place efficiency testable HEPA filter systems are employed.

TABLE 1-4

Relatively Long-Lived Transuranic Isotopes

Symbol/Element	Isotope	Half-Life*	Radiotoxicity**
93 (Np) Neptunium	234	4.4 days	-
	235	410 days	-
	236	>5000 years	1
	237	2.14E6 years	2
	238	2.10 days	-
	239	2.35 days	-
94 (Pu) Plutonium	236	2.85 years	-
	237	45.6 days	-
	238	86.4 years	1
	239	2.44E4 years	1
	240	6580 years	1
	241	13.2 years	1
	242	3.79E5 years	2
	244	7.6E7 years	-
95 (Am) Americium	241	433 years	1
	242m	152 years	1
	243	7700 years	1
96 (Cu) Curium	240	26.8 days	-
	241	35 days	-
	242	163 days	1
	243	32 years	1
	244	17.6 years	1
	245	9320 years	1
	246	5480 years	1
	247	1.6E7 years	1
	248	4.7E5 years	-
	250	1.7E4 years	-
97 (Bk) Berkelium	247	1.4E3 years	-
	249	314 days	1
98 (Cf) Californium	248	350 days	-
	249	360 years	1
	250	13 years	1
	251	800 years	-
	252	2.65 years	1
	253	17.6 days	-
	254	60.5 days	-

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* Source : Ref 1-4.

* Radiotoxicity class given in Ref 1-2; (-) denotes not specified.

Other Particulates

The fission and activation products (FAP) constitute the major part of the radionuclides in this category. The FAP can be considered to fall under the general heading of by-product material. Table 1-5 lists major fission and activation products encountered at nuclear facilities.

At a university, hospital, or industrial laboratory, where sealed sources are being handled, no control technology is required. However, when unsealed materials are being handled and the quantities in question are in the microcurie to millicurie range, a fume hood, with appropriate ventilation and ventilation control technology (usually HEPA filters) may be utilized. As the quantity and/or the relative radiotoxicity of the material increases, incrementally more stringent measures are employed. For example, if millicurie quantities of strontium-90 are being handled in a research laboratory, then pressure zonation, glove box handling, and inlet and outlet HEPA filters are employed.

At nuclear fuel cycle facilities, the control technology for reduction of airborne emission of particulate fission and activation products is HEPA filters preceeded by pre-filters and/or scrubbers. Sand filters are also employed at National Laboratories.

Gases

This section considers the existing technologies utilized to control the airborne emission of gaseous radionuclides. Halogens and semi-volatile radionuclides (such as ^{106}Ru) will also be considered in this section since they can exist in gaseous form. Many different types of technologies are utilized to control airborne emission of gaseous radionuclides. Among these are scrubbers, delay systems, adsorption beds, and catalytic recombiners. These tech-

TABLE 1-5

Major Long-Lived Fission and Activation Products

Symbol/Element	Isotope*	Half-Life	Radio-toxicity**
89 (Ac) Actinium	227	21.2 years	3
51 (Sb) Antimony	122	2.8 days	2
	124	60.2 days	2
	125	2.7 years	2
33 (As) Arsenic	74	17.9 days	3
	76	26.4 hours	3
	77	38.7 hours	3
56 (Ba) Barium	131	12.0 days	3
	137m	2.55 minutes	2
	140*	12.8 days	2
4 (Be) Beryllium	7	53 days	3
83 (Bi) Bismuth	210	5 days	2
48 (Cd) Cadmium	109	453 days	2
	115	43 days	3
20 (Ca) Calcium	45	163 days	2
	47	4.5 days	3
6 (C) Carbon	14	5730 years	4
58 (Ce) Cerium	141	32.5 days	3
	144*	285 days	2
55 (Cs) Cesium	134	2.1 years	2
	137*	30 years	2
17 (Cl) Chlorine	36	30000 years	4
24 (Cr) Chromium	51	27.8 days	4
27 (Co) Cobalt	58	71 days	2
	60	5.24 years	2
29 (Cu) Copper	64	12.9 hours	3
63 (Eu) Europium	152	12.4 hours	2
	154	16 years	2
31 (Ga) Gallium	72	14.1 hours	3
32 (Ge) Germanium	71	11 days	4
79 (Au) Gold	196	6.2 days	3
	198	64.8 hours	3
	199	31.5 days	3
72 (Hf) Hafnium	181	43 days	2
67 (Ho) Holmium	166	27.2 hours	3
	170	45 seconds	3
49 (In) Indium	114	50 days	2
77 (Ir) Iridium	192	74.2 days	2
	194	17.4 hours	3
26 (Fe) Iron	55	2.4 years	3
	59	45 days	2
57 (La) Lanthanium	140*	40.2 hours	3
82 (Pb) Lead	203	52 hours	4
71 (Lu) Lutetium	177	6.7 days	3
25 (Mn) Manganese	53	5.7 days	3
	54	312 days	3
	56	2.58 hours	3
80 (Hg) Mercury	197	65 hours	3
	203	46.9 days	2
42 (Mo) Molybdenum	99	67 hours	3

(continued)

TABLE 1-5 (continued)

Symbol/Element	Isotope*	Half-Life**	Radio-toxicity***
60 (Nd) Neodymium	147*	11.1 days	3
28 (Ni) Nickel	59	8×10^4 years	4
	63	92 years	2
41 (Nb) Niobium	95	35 days	3
76 (Os) Osmium	191	15 days	3
46 (Pd) Palladium	103	17 days	3
	109	13.5 hours	3
15 (P) Phosphorus	32	14.3 days	2
78 (Pt) Platinum	191	3.0 days	3
	193	<500 years	3
84 (Po) Polonium	210	138.4 days	1
19 (K) Potassium	42	12.4 hours	3
59 (Pr) Praeso-dymium	142	19.2 hours	3
	143*	13.7 days	3
	144	17.3 minutes	2
	147*	12 minutes	2
75 (Re) Rhenium	186	90 hours	3
45 (Rh) Rhodium	105	36 hours	3
	106	2.2 hours	2
37 (Ru) Rubidium	86	18.7 days	2
62 (Sm) Samarium	151*	90 years	2
	153	47 hours	3
21 (Sc) Scandium	46	83.8 days	2
	47	3.4 days	3
	48	44 hours	3
34 (Se) Selenium	75	120 days	3
47 (Ag) Silver	105	40 days	2
	110	24.4 seconds	2
	111	7.5 days	3
11 (Na) Sodium	22	2.60 years	2
	24	15.0 hours	3
38 (Sr) Strontium	85	65 days	3
	89	50.6 days	2
	90*	28.8 years	1
16 (S) Sulfur	35	86.7 days	3
73 (Ta) Tantalum	182	115 days	2
43 (Tc) Technetium	98	1.5×10^6 years	4
	99*	2.1×10^5 years	4
52 (Te) Tellurium	127*	105 days	3
	129*	34 days	4
50 (Sn) Tin	113	118 days	2
81 (Tl) Thallium	200	26 hours	3
	201	73 hours	3
	202	12.4 days	3
	204	3.75 years	2
69 (Th) Thulium	170	125 days	2
74 (W) Tungsten	181	130 days	3
	185	74 days	3
	187	24.0 hours	3
23 (V) Vanadium	48	16.1 days	2
39 (Y) Yttrium	90	64.2 hours	3
	91*	59 days	2
30 (Zn) Zinc	65	243 days	2
40 (Zr) Zirconium	95*	65 days	2

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* Most of the isotopes are activation products or daughters of fission products. Those denoted by (*) can result directly from fission (Ref 1-4).

** Half-lives given in Ref 1-4.

*** Radiotoxicity class defined in Ref 1-2.

technologies, which are more fully discussed in Chapter II, are summarized below.

Scrubbers that utilize chemical interaction between the scrubbing medium and the contaminant, such as the mercury nitrate-nitric acid scrubbers and caustic scrubbers, can also remove certain types of gases from the effluent. Mercury nitrate-nitric acid scrubbers remove iodine species from gaseous effluents with experimentally determined efficiencies that range from 90% to 99.99%. Caustic scrubbers are effective in removing non-organic iodine species with experimentally determined efficiencies ranging between 99% to 99.99%, and in removing ruthenium species with experimentally determined efficiencies up to 99%. However, caustic scrubbers are less efficient in removing organic iodines and particulates.

Delay systems are primarily utilized for the control of short-lived noble gases and other gaseous radioisotopes, however, delay times of up to 90 days in some systems (pressurized storage tanks) result in the decay of some of the longer-lived radioisotopes as well. Pressurized storage tanks are primarily utilized in central station nuclear power plants. Simpler forms of delay systems, such as hold-up piping, Douglas Bags, and delay of ventilation, are used at other nuclear facilities. Efficiencies of the delay systems for specific radionuclides are determined by the decay of the radionuclide during the hold-up duration of the system.

There are several kinds of adsorption beds such as: charcoal beds (also called charcoal filters) which are usually activated/impregnated with triethylene diamine (TEDA) or potassium iodide (KI) or iodine gas to enhance their adsorbtion capability; molecular sieves such as silver zeolite beds; alumina (Al_2O_3) traps which are usually impregnated with silver oxide or silver nitrate, and macroreticular resin beds which are insoluble polymer beads with discrete pores ranging from 50 to 200,000 angstroms. These control systems, which basically are special kinds of filters, utilize chemical reactions between the contaminant and the adsorbing medium to remove the contaminant. They are primarily utilized to remove organic and inorganic iodine species and other halogens. However, they also exhibit some removal capability for noble gases. Efficiencies of these systems depend on the operating conditions, e.g., high humidity adversely affects charcoal systems, and cation poisoning may reduce silver zeolite efficiency. Under suitable conditions, efficiencies for iodine removal of greater than 99% have been reported.

Catalytic recombiners are used primarily to remove hydrogen species, including tritium, from system effluents. They utilize a catalyst, such as platinum/palladium, to combine hydrogen and oxygen at elevated temperatures (about 300° to 350°F).

The existing airborne emission control technologies for gaseous radionuclides will be discussed below in four major categories: radon and thoron, noble gases, halogens, and other gaseous radionuclides.

Radon and Thoron

Radon (^{222}Rn) and Thoron (^{220}Rn) are noble gas daughters of ^{226}Ra and ^{224}Ra (see Tables 1-1 and 1-3) that occur during the decay of the ^{238}U and ^{232}Th chains, respectively. Both radionuclides decay by alpha particle emission to short lived radon isotopes. Their half-lives are 3.82 days for ^{222}Rn and 51.5 seconds for ^{220}Rn.

Of the facilities considered in Chapter II, only uranium mines and mills, and spent-fuel reprocessing facilities include ^{222}Rn as a potential airborne effluent radionuclide.

There are no airborne emission control technologies in use at uranium mines and mills that are specifically designed to reduce ^{222}Rn emissions. Information on the effects of particulate control systems on ^{222}Rn emissions could not be obtained. However, techniques such as bulkheading and backfilling have been used, routinely, in underground uranium mines to improve ventilation and reduce ^{222}Rn concentrations in mine atmospheres, and the use of an autogenous or semi-autogenous grinder probably reduces the amount of ^{222}Rn released during grinding operations.

Current NRC guidelines require that, after the milling operations have ceased, the release of ^{222}Rn per unit area from uranium mill tailings be reduced to a maximum of 2 pCi/sec-m^{2} in addition to background emanation. This goal will be attained by the use of a cover material whose physical characteristics will limit ^{222}Rn diffusion.

Of the facilities considered in Chapter II, only HTGR spent-fuel reprocessing facilities include ^{220}Rn as a potential airborne effluent radionuclide.(1-11) Because of the short half-life of ^{220}Rn, delay systems are applicable for reduction of ^{220}Rn emissions.

Noble Gases

Noble gases are elements characterized by their very limited chemical behavior: neon, argon, krypton, xenon, and radon. The relatively limited behavior of the noble gases results from the completely filled outer "p" electron shell. The radioisotopes of radon was considered previously. Other major radioactive isotopes of noble gases, which occur in the airborne effluents of nuclear facilities, are presented in Table 1-6.

Because of the very limited chemical behavior of noble gases, the principal technology for control of noble gas radioisotopes is the delay system. However, other technologies that utilize chemical removal principles also reduce noble gas emissions to some degree. Information on the removal efficiencies of these technologies, such as

TABLE 1-6

Major Noble Gas Radioisotopes

Symbol/Element	Isotope*	Half-Life**	Radiotoxicity***
18 (Ar) Argon	37	35.1 days	4
	41	1.83 hours	-
36 (Kr) Krypton	83m	1.86 hours	-
	85*	10.74 years	4
	85m*	4.4 hours	-
	87*	76 minutes	-
	88*	2.79 hours	-
	89*	3.18 minutes	-
54 (Xe) Xenon	131m	11.9 days	-
	133m*	2.26 days	-
	133*	5.27 days	4
	135m*	15.7 minutes	-
	135*	9.16 hours	-
	137	3.82 minutes	-
	138	14.2 minutes	-

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* Those isotopes denoted by (*) can result directly from fission (Ref 1-4). Others are activation products or daughters of fission products.

** Half-lives given in Ref 1-4.

*** Radiotoxicity class defined in Ref 1-2; (-) denotes not specified.

chemical scrubbers and activated charcoal filter systems, in addition to the removal afforded by the delay within the system, could not be obtained.

In central station nuclear power plants, elaborate delay systems composed of some combination of pressurized storage tanks, hold-up piping and activated charcoal filter systems are utilized. In accelerators or fusion devices, holding the activated gas in place during operations and venting after a certain time results in hold-up confinement. At hospitals, where radioxenons such as ^{133}Xe are employed in diagnostics and therapeutics, hold-up confinement (Douglas bags) and charcoal filter systems are sometimes employed.

Halogens

Halogens are elements which are non-metallic and negative monovalent: fluorine, chlorine, bromine, and iodine. Their similarity in chemical behavior results from the single electron deficiency of the outer "p" electron shell. Major radioactive isotopes of halogens, which occur in the airborne effluents of nuclear facilities, are presented in Table 1-7.

Organic and inorganic adsorption technologies, such as activated charcoal filter systems, molecular sieves, and alumina traps, are the principal technologies utilized for control of airborne emissions of halogens. These are utilized in central station nuclear power plants, reprocessing facilities (1-13, 1-14, 1-15), and waste management facilities. Delay systems, which are utilized in central station nuclear power plants, also result in reduction of emission of the shorter half-lived radioisotopes. Chemical scrubbers, such as caustic scrubbers, are also used for the removal of radioiodine species.

TABLE 1-7

Major Halogen Radioisotopes

Symbol/Element	Isotope*	Half-Life*	Radiotoxicity***
9 (F) Fluorine	18	110 minutes	4
35 (Br) Bromine	82	35.3 hours	3
53 (I) Iodine	129*	1.6E9 years	-
	131*	8.06 days	2
	132*	2.26 hours	4
	133*	20.8 hours	-
	134*	52.0 minutes	-

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* Those isotopes denoted by (*) can result directly from fission (Ref 1-4). Others are activation products or daughters of fission products.

** Half-lives given in Ref 1-4.

*** Radiotoxicity class defined in Ref 1-2; (-) denotes not specified.

Other Gases

Other radionuclides that may exist in gaseous form in the airborne effluents of nuclear facilities are given in Table 1-8.

Catalytic recombiners are the principal technology for removal of gaseous tritium from airborne effluent streams. Chemical scrubbers may be utilized for the removal of ^{14}C. Delay systems are utilized at central station nuclear power plants for the reduction of short half-life isotopes of oxygen and nitrogen.

Semi-volatile radionuclides are those that can be encountered in gaseous form under certain operating conditions, e.g., at elevated temperatures gaseous streams from reprocessing facilities have been found to contain ruthenium, cesium, and antimony. Chemical scrubbers are utilized in removal of semi-volatile radionuclides from gaseous streams. Decontamination factors of 10 have been reported for caustic scrubbers. Another combination, caustic scrubber in series with an acid scrubber (mercury nitrate-nitric acid) followed by a HEPA filter, reportedly provides a decontamination factor of 10^9 for ruthenium.

TABLE 1-8

Other Major Radioactive Gases

Symbol/Element	Isotope*	Half-Life**	Radiotoxicity***
1 (H) Hydrogen	3*	12.26 years	4
6 (C) Carbon	14	5730 years	3
7 (N) Nitrogen	13	10 minutes	-
	16	7.13 seconds	-
	17	4.14 seconds	-
8 (O) Oxygen	14	71 seconds	-
	15	123 seconds	-
	19	29 seconds	-
44 (Ru) Ruthenium+	97	2.88 days	4
	103*	39.5 days	2
	106*	368 days	2

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* Those isotopes denoted by (*) can result directly from fission (Ref 1-4). Others are activation products or daughters of fission products.

** Half-lives given in Ref 1-4.

*** Radiotoxicity class defined in Ref 1-2; (-) denotes not specified.

+ Ruthenium is often referred to as semi-volatile element; it can exist in gaseous form.

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CHAPTER IV

Section 1: Introduction

This chapter reviews advanced control technologies which may be used to reduce radiological particulate and radioactive gaseous emissions. The review includes both devices and, where applicable, process improvements. The format of the chapter is similar to that of Chapter II. Research and development for potential use by the uranium mining and milling industry is reviewed first. This is followed by a review of advanced systems for the remainder of the nuclear fuel cycle. The final section deals with novel particulate control research. The novel devices are primarily those useful in controlling the respirable fraction of particulate emissions. Appendices to the chapter include a catalog of the research investigated.

CHAPTER IV

Section 2: Available But Not Yet Applied Control Technologies for Uranium Mines and Mills

The purpose of this section is to identify those systems for reducing radioactive gaseous and particulate effluents that have a high potential for use in the uranium industry but have not been commercially used. Systems considered include engineered systems of emission reduction, process improvements and engineering solutions. Engineered systems are defined as emission reduction systems that have been demonstrated by prototype systems and are known to be scalable to usable sizes. Process improvements and engineering solutions are those that would not require development (such as returning mill tailings to mines) and have undergone limited testing. The systems of effluent reduction described in this section are categorized by application to a source, and where possible, data is presented on costs, effectiveness, solid and liquid wastes, and energy consumption.

Identification of those systems of effluent reduction which have a high potential for use by the uranium industry was accomplished through a review of the available technical literature and through inquires made to knowledgeable individuals in agencies of government, primarily the Nuclear Regulatory Commission and the Department of Energy, and in the uranium industry.

Uranium Mines

Engineered Systems of Effluent Reduction

Conversations with individuals in government and the industry, and review of the available literature indicate that there are no specific engineered systems of emission reduction available, at the present time, that have a high potential for direct application to radioactive particulate or gaseous emissions from surface or underground uranium mines. Air cleaning techniques that might inadvertently reduce radioactive emissions were also investigated. They included use of sealants, filters, over-pressurization and electrostatic precipitation. The use of sealants and over-pressurization to control radon-222 emissions from underground uranium mines are not discussed further since review of the literature indicates that both techniques require more R&D work.

Uranium Mine Atmospheric Control Technology

As stated in Chapter II, Section 2, the primary means of reducing working levels in an underground uranium mine atmosphere is by dilution with air from above ground. As mines become deeper in an attempt to recover uranium ore from economically feasible deposits, the efficiency of the mine atmosphere ventilation technique is expected to decrease while the costs increase.(2-1)

The basic components of mine ventilation system are few in number and simple in design. The fans of the primary ventilation system (forced air type) are located at ground level and are designed to either push air down the shafts into the mine workings (down-cast type fan) or to pull the air through the mine and out the shaft (up cast type fan). Flow rates within the primary air system of uranium mines are commonly on the order of 500,000 cfm. However, it has been reported that one large Canadian mine (unspecified) has a primary flow rate of nearly 2 million cfm.(2-2) Secondary ventilation systems, using auxillary fans, direct portions of the primary air flow to specific working areas.

In addition to controlling build-up of radionuclides in the mine atmosphere by ventillation, there are specfic technologies that address radon daughter control. These include electronic air cleaners and air filtration systems.(2-2, 2-3, 2-4) Both systems have been evaluated for the purpose of research and development in operational mines. The systems will be discussed separately.

Electronic Air Cleaning Systems

Several uranium mining companies have reportedly used standard industrial type electrostatic precipitators (ionizing plate-type) to reduce radon-daughter and dust concentrations in the mine air streams.(2-2, 2-3) The precipitators were installed in modules across the primary airways, at the intakes to the auxillary air system and in underground offices. Data on the length of service of these units are not available. However, it is reported that electronic air cleaning systems were used in one mine for approximately seven years.(2-2)

Data on radon-daughter removal efficiencies are minimal at best. The data that are available are for Westinghouse Mark I and Model PM Precipitator air cleaners, the production of which has been discontinued. The radon-daughter removal efficiencies attained were found to be less than the manufacturer rated efficiency for dust. This is expected since particle size distribution studies indicate that a large fraction of the radon daughter activity is associated with particles with diameters of less than a few tenths of a micron.(2-2) The reported efficiencies ranged from 95+ percent to 65 percent for face velocities of 250 ft/min and 500 ft/min, respectively.(2-2) No data were found on the costs, non-air impacts, energy consumption and effects of these units on radon-daughter emissions from the mine.

Inquiries made of sources in the uranium industry revealed that these units were found to be unreliable and inefficient in mines where the moisture content of the mine atmosphere was high. Until it is shown that these units can be operated under high humidity conditions, the probability of use is extremely low in mines with elevated humidity.

Filtration

Programs to evaluate the feasibility of using filtration equipment to reduce radon-daughter concentrations have been conducted at uranium mines in the Ambrosia Lake district of New Mexico, in southwestern Colorado, and at the Dension Mines at Elliot Lake, Ontario.(2-2) Feasibility data are available for only the Dension Mines test.

The tests included evaluation of commercially available fibrous filters and specially designed sand filters. The results are presented in Table 2-1. For all commercially available fibrous filters except the Micretain Filter & Renu Klean Prefilter the advertised efficiency (regardless of method of determination) is significantly greater than the actual measured radon-daughter removal efficiencies. Filters with manufacturer's efficiency rating between 90-99% showed a radon daughter removal efficiency range of 24-84%.

The Dension Mine personnel also evaluated the filter characteristics of filters made of poly-urethane foam chips, fabric filters made of polyethylene terephalate and filters made of vermiculite.(2-2, 2-4) The average radon daughter removal efficiencies of vermiculite were low relative to the other filters tested. Vermiculite had a radon daughter removal efficiency of 40-60% while the polyurethane and polyethylene terephalate filters had removal efficiencies of 80% and 90% respectively.

No data were found on the costs,non-air impacts, and energy consumption of these units. The effects of these units on radon daughter emissions from the mine could not be determined.

The major problems associated with the use of filters for cleaning mine atmospheres have been 1) sorption of moisture that leads to rapid clogging and/or loss of the filters structural strength and 2) high replacement and maintenance costs.(2-6)

TABLE 2-1

Summary of Underground Filter Testing

Filter	Flow Rate		Face Vel.	Main Filter Pressure Drop (in W.G.)		Total Cu. Ft. Thru Filter	Av. Dust Removal (%)		Av. Rn. Dtrs. Removed	Av. Total Dust Load	Advertised Eff. (%)			Remarks
	Rated CFM	Tested CFM (av.)	(FPM)	Initial	Final	$x10^6$	Total	Respirable	(%)	(MG/M^3)	Arrestance Method	Dust Spot	DOP	
A. Sand Bed Filter (3'x4')														
1) 5" th. 2M Sand	--	300	25	1.0	2.0	7.28	50	55	60	0.42	--	--	--	Thickness of bed = 5 inches Filter media = 2 M New Jersey silica s Effective size = 0.8-1.2 MM, uniformit coeff. = 1.6
2) 7" th. 1M Sand	--	225	19	2.5	4.0	9.45	80	86	85	0.33	--	--	--	Thickness of bed = 7 inches Filter media = 2 M N.J. silica sand E.S. = 0.6 to 0.8 MM, U.C. = 1.6
B. Fibrous Filters[a] (2'x2')														
1) Micretain + Renu Klean Prefilter	600	523	130	0.47 (0.5)[b]	5.90 (1.0)[b]	5.87	98	99	97	1.34	—	99	95	Incr. In Wt. (gms.) Main: 206 solids, 143 water; Pre: 25 solids, 0 water Main Filter - Cambridge Prefilter - American Air Filter (AAF)
2) Fram + Furnace Prefilter	1000	750	187	2.40	4.65	2.16	64	63	47	1.51	99	--	--	Main Filter - Fram Corp. Prefilter - Canadian permanent Replacement Filter
3) Airmat PL-24	1000	625	156	0.24	4.00	6.98	46	38	24	1.79	92	40	--	AAF - Fram Filter Media (renewable) Type 15 Treated 10 ply
4) MSA Air-O-kay Prefilter	1000	1000	250	0.10	0.14	4.32	9	9	10	0.76	--	--	--	MSA prefilter - life short because filter perforated
5) Furnace Prefilter	--	1250	360	0.18	0.25	9.00	22	16	9	2.67	--	--	--	As 2 above, purchased from Canadian Tire, Elliot Lake, size 20"x25"

TABLE 2-1 (cont'd)

	Filter	Flow Rate		Face Vel.	Main Filter Pressure Drop (in W.G.)		Total Cu. Ft. Thru Filter	Av. Dust Removal (%)		Av. Rn. Dtrs. Removed	Av. Total Dust Load	Advertised Eff. (%)			Remarks
		Rated	Tested	(FPM)	Initial	Final	$x10^6$	Total	Respirable	(%)	(MG/M^3)	Arrestance Method	Dust Spot	DOP	
6)	Airmat 16 ply, experimental	—	850	212	3.14	--	perforated	38	26	13	2.57	--	--	--	Non-pleated 4 sq. ft. tested on wooden frame, used 2, 8 ply (IS)
7)	Foam Plastic	--	300	75	0.45	3.40	3.58	50	34	41	2.36	--	--	--	Purchased from Simpsons Sears. 2" thick, fine pored
8)	'Felt' 1/16" th.	—	375	94	3.30	5.80	flow = 0 at final	--	--	43 clean	—	--	—	--	Supplier 'Micro-Air', material probably terylene or polypropylene
9)	MSA Dust-foe + Air O-Kay Pre-filter	2000	1750	437	0.50	5.40	19.94	65	73	84	1.61	—	90-95	--	Main filter B-2000 Model, incr. in wt = 760 gms. (Design 2400 gms @ 1.0" wg. final)
10)	DriPak 2040 + Renu Klean Pref.	2500	2290	572	0.20 $(0.30)^b$	0.70 $(0.75)^b$	45.75	29	33	16	1.14	85	40	--	Both AAF products Incr. in wt. = 280 gms. (Design 610 gms)
11)	HV2 - Viscous Impingement Filter	2000	1990	497	0.15 $(0.10)^b$	0.55	51.21	14	8	5	1.52	--	--	--	AAF Product, coated with one gallon of viscosine adhesive before testing.
12)	Pliotron HD	1080	240	60	<0.1	<0.1	0.1	—	--	3	--	--	50	--	Pliotron self charging filter. Efficiency increased to >16% when Wheelabrator filter aid added.

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a. Fibrous Filters; Filters No. 1,2,3,4,9,10,11,12 = commerical filters: filters No. 5,6,7,8 = experimental filters.

b. Recommended pressure drop at rated flow.

Source: Reference

As in the case with electrostatic precipitators, the probability of use of these devices is low until it is shown that the units can operate efficiently in high humidity atmospheres.

Process Improvements

Review of the available technical literature has resulted in the identification of a mining technique that may reduce radioactive particulate and gaseous emissions from selected uranium mining operations. The technique is called hydraulic borehole mining or slurry mining and uses a water jetting system in conjunction with a slurry pumping system to extract uraniferous sandstones from subsurface deposits. The equipment for this mining process was developed and the economic feasibility of the technique was demonstrated by the U.S. Department of the Interior, Bureau of Mines.(2-7)

The mining process involves the use of a high pressure water spray to create a uraniferous sandstone slurry that is pumped to the surface by the use of a slurry pump system. At the surface the ore is separated from the water and the water is returned to the water jet system for reuse. The ore is then transported to the mill area for processing.

Although no environmental data are currently available, the overall radiological impact of this technique on the environment is expected to be small relative to the open-pit and shaft techniques. Use of the wet system will minimize gaseous and particulate emissions during mining. The solids within the slurry are grain sized and are directly compatible with standard mill grinding circuits. Use of crushers would not be required, thereby eliminating a potential emission source during milling. It is currently speculated that the tailings produced from the mill could be pumped into the mined out areas, if it were shown to be hydrologically and environmentally feasible. If this method were found feasible, the problems of wind erosion of tailings, radon-222 emanation and tailings reclamation could be significantly reduced for these ore bodies to which this technique can be applied.

The hydraulic borehole mining system was field tested by Rocky Mountain Energy Corporation at their Nine Mile Lake site located in Natrona County, Wyoming. The results of these tests indicated that the technique is currently economically feasible for the mining of uraniferous sands with cut off grades of 0.06 percent U_3O_8 at depths of 100 feet or less.(2-7)

No data were found on the costs, radiological impacts, non-air effects or energy consumption requirements of the technique.

Uranium Mills

Process Improvements

Holmes & Narver, Inc. has developed a leach process that is applicable to both the uranium and copper industries.(2-8, 2-9, 2-10) and which may reduce radioactive emissions from the tailings. The process, called thin layer leaching, uses variations of several standard milling procedures including:

a) crushing the ore to a size of approximately one-quarter of an inch

b) mixing the crushed ore with strong acid in a rotating drum to obtain a moisture content of approximately 10%

c) curing the mix in piles for approximately 24 hours

d) layering the ore in three foot thick beds

e) spay leaching the beds with "rinse" solutions consisting of either water or raffinate

The pregnant solution is passed through standard solvent extraction/ion exchange circuits to recover the uranium. The solid residual in the cure pile is then removed and disposed of by burial either in the mine or at a selected tailings disposal site. A process flow diagram is shown in Figure 2.1.

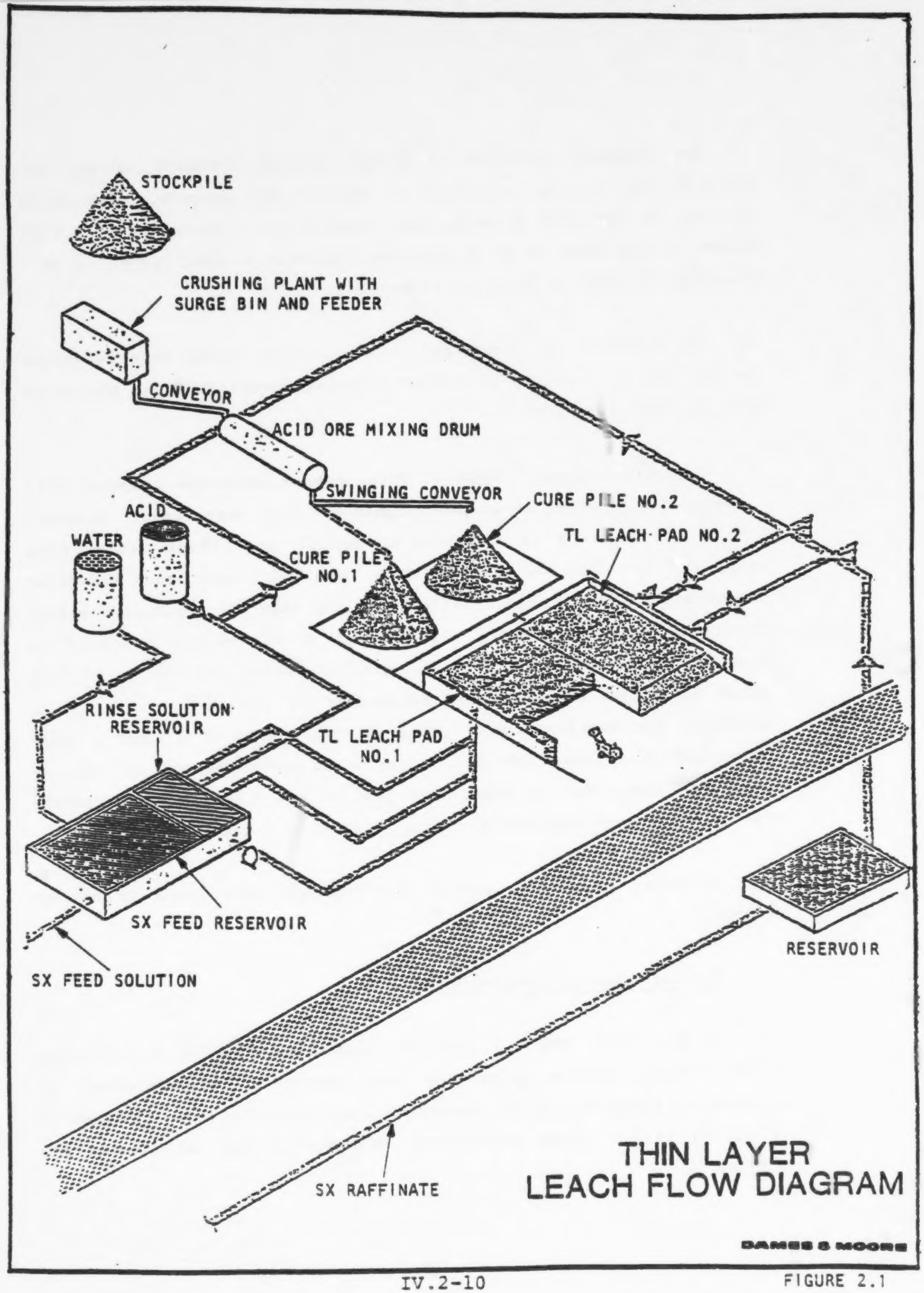
The economic and technical feasibility of using this technique for uranium ore milling is currently being investigated at the Atlas mill in Moab, Utah.(2-8)

The environmental impact of this process technique compared with a standard aggitation leach process has not been determined. However, use of the process is expected to result in a lower radioactive emissions rate from the tailings area. The thin-layer leach technique produces a coarser grained residual tailing than the residual tailings generated from a standard uranium mill. The coarse residual is expected to reduce fugitive dust emissions since the number of fine sized particles available for suspension by the wind, is low. In addition, the coarse-sized residual is anticipated to produce a lower radon-222 flux since the coarse particles are expected to have an emanation power that is lower than that of the finer tailings generated by a standard crushing/grinding circuit at a uranium mill.

No other potential process improvements were found to be relevant.

Tailings Control Technologies

In May 1977, the U.S. Nuclear Regulatory Commission licensing staff issued interim guidelines that addressed the management of uranium tailings during the operational and post-operational stages of a mill's life. These guidelines include, but are not limited to: (2-11)


STOCKPILE
CRUSHING PLANT WITH SURGE BIN AND FEEDER
CONVEYOR
ACID ORE MIXING DRUM
SWINGING CONVEYOR
CURE PILE NO.2
TL LEACH PAD NO.2
ACID
WATER
CURE PILE NO.1
RINSE SOLUTION RESERVOIR
TL LEACH PAD NO.1
SX FEED RESERVOIR
SX FEED SOLUTION
RESERVOIR
SX RAFFINATE
DAMES & MOORE

THIN LAYER
LEACH FLOW DIAGRAM

FIGURE 2.1

o Elimination of tailings being blown to an unrestricted area during normal operating conditions.

o Reduction of gamma radiation levels from the tailings impoundment area to essentially background following reclamation.

o Reduction of the radon flux from the tailings impoundment area to twice background following reclamation.

o Elimination of the need for long term monitoring and/or maintenance following reclamation.

As of this writing, new guidelines have been proposed (2-12) which include:

o Reduction of the radon-222 flux, as measured at the surface of the reclaimed tailings, to less than 2 pCi/m^2-sec above background.

o The reclaimed tailings shall have a minimum cover thickness of not less than 3 meters.

The following section discusses the systems of radioactive airborne effluent reduction, as proposed by the industry, which have a high potential for use but have not been put into use at the present time. This discussion is limited to engineering solutions since no experimental data could be found. The tailings disposal and reclamation alternatives discussed are those that are considered technologically and economically feasible under existing guidelines. Implementation of new guidelines may or may not significantly alter the list of economically viable alternatives.

Currently Proposed Tailings Disposal/Reclamation Alternatives

As a result of federal guidelines, three general uranium tailings disposal/reclamation concepts have been proposed by the industry. These concepts are 1) disposal of tailings above grade, 2) disposal below grade and 3) disposal in mined-out sections of the mine.

Alternative I: Disposal of Tailings Above-Grade in Topographic Lows

In this disposal method the tailings are pumped to a topographic low that is bounded on at least three sides by significantly higher topographic features. The fourth side would be a man-made dam. The low is lined with a minimum of three feet of impermeable clay to prevent seepage of tailings water. The tailings are disposed of until the site is filled. The discharged tailings would be permitted to separate into sands and slimes fractions by natural means.

Variations of this general concept include disposal into a topographic basin, therefore eliminating the need for a man-made dam.

Regardless of the exact disposal technique employed during the operational phase of the facility, applicable guidelines would be met through use of a water spray system or crusting agent to limit fugitive dust emission from the sands and a water cover which would be maintained over the slimes to eliminate wind erosion.

Reclamation of the tailings would be initiated when the tailings are sufficiently dry to permit the safe use of heavy equipment. Reclamation would be accomplished by covering the tailings with a cover of natural materials thick enough to meet existing guidelines. The amount of cover required is a function of such parameters as tailings radon-222 flux at the time of reclamation, the porosity, moisture content, radon-222 diffusion coefficient, emanation power and radium-226 concentration.

Alternative II: Disposal of Tailings in Below-Grade Impoundments

Below-grade disposal involves the construction of individual impoundment cells (a series of trenches) partially or totally below grade level. This disposal scheme requires simultaneous construction, operation, and reclamation of the cells. The individual cells are lined either with clay or an impermeable membrane to prevent seepage laterally and/or horizontally. Each cell is designed to hold that quantity of tailing generated by the milling activities during a fraction of the mill life e.g., 2-5 years worth of mill tailings. As one cell is being used for disposal of tailings, the previously used cell is permitted to dry while the next cell is waiting to be put into operation and simultaneously is used as an emergency catchment. Operational dust control and reclamation would be accomplished by those techniques stated in Alternative I. However, part of the materials used for reclamation of the cells containing dried tailings could be material excavated from the construction of cells coming on-line if this material is found to be economically and technically suitable. The thickness of cover material required is dependent on those parameters cited for Alternative I.

Alternative III: Disposal of Tailings into Mined-out Areas of the Uranium Mine

This alternative requires the transportation of mill generated tailings to the mine and emplacement of tailings in sections of the mine from which all the ore has been removed. Transferring the tailings from the mill would be accomplished either by use of a slurry pipe line system or, if dried at the mill, by truck.

Implementation of this alternative in an operational underground mine would not require significant tailings reclamation activities other than backfilling and use of bulk heads. Disposal in open-pit mines would require a higher degree of reclamation than disposal in an underground mine. However the reclamation for the tailings themselves would not be as extensive as the reclamation cited for Alternatives I & II.

Two of the three generalized tailings disposal/reclamation alternatives that were discussed require use of a finite thickness of cover material to achieve the guideline objectives. A number of analytical models exist to calculate this thickness. One such model is reproduced in Appendix IV-A.

Conclusion

Review of the available technical literature and conversations with individuals in industry and government have indicated that at the present time, there are no control technologies currently available for reducing radionuclide emission from uranium mines and mills (excluding tailings) that have a high potential for use.

The major emission control technology under active consideration by the industry is the use of a finite thickness of cover material to reduce radon-222 emissions from the tailings to applicable guideline limits.

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CHAPTER IV

Section 3 : Conceptual But Not Yet Demonstrated Control Technologies Applicable to Uranium Mines and Mills

Introduction

The following section identifies conceptual control technologies that might be applicable to controlling radioactive airborne effluent emissions from uranium mines, mills and mill tailings. The systems described in this section have not been shown to be technically and economically feasible on pilot scale or operating facilities. Advanced particulate emission control systems applicable to uranium mills are not identified in this section since the data obtained from federal agencies and industry representatives indicate that there are no advanced systems of particulate emission controls being developed specifically for the uranium industry. It is assumed that the fundamental principles of the control systems identified in the final section of this chapter would be equally applicable to the particulate emissions from uranium mills and mines. However, the technical and economic feasibility of using these controls on uranium mine and mill effluents has still to be investigated.

The major emphasis of this section is on those systems which are potentially applicable to the control of Radon-222 emissions from uranium mines, mills and mill tailings.

Radon-222 Control Technology - Mine Effluents

At the present time, there are no conceptual control systems for removal of radon-222 from mine exhausts under investigation. Research and development activities are currently being conducted by the Bureau of Mines (Department of the Interior) on techniques which may be utilized to reduce radon-222 concentrations in underground mine atmospheres. These control systems include techniques for reducing radon-222 flux from the mine walls; removal of radon-222 from ventilation air entering a working area and; control of radon-222 leakage from mined-out areas into the ventilation air passageway. The quantitative effects of these techniques on the radon-222 concentrations in mine exhaust air are unknown. A discussion of these techniques is presented since their use will probably alter the radon-222 characteristics of the mine discharge.

Radon-222 Emanation Reduction by Polymeric Sealants

The U.S. Bureau of Mines is conducting research into the use of various polymeric materials for reducing radon emanation from underground mine walls.(3-1, 3-2) Tests have been conducted in the laboratory and under field conditions in non-operational underground mines in New Mexico and Colorado. As of 1975, a total of forty-six materials had been tested. Two of these materials*, HydrEpoxy 156 and HydrEpoxy 300, have undergone detailed field studies.(3-2)

Comparison of the laboratory test data and the field test results indicate that field conditions may significantly alter the ability of a material to inhibit radon emanation. Ore samples coated with various sealants have, under laboratory conditions, shown a 90-95 percent effectiveness in stopping emanation, even after a period of nine months.(3-1) However, field measurements of the ability of these materials to reduce radon-222 emantion have indicated that the coatings have an emanation stopping efficiency of 50-65% soon after application and a stopping efficiency of 75% after a year.(3-2) The effectiveness of the sealant's ability to reduce radon flux from mine walls was initially considered to be dependent on the barometric change within the mine atmosphere.(3-3) However, statisical analysis of the data on the effects of sealants on radon flux has indicated that the use of a sealant decreases the barometric effect on radon flux.(3-4)

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*Two water-based epoxies manufactured by Acme Chemical and Insulation Co. Commercial names are for identification only.

The 1977 material costs associated with these tests, including sealants and shotcrete, ranged from $0.30 to $1.19 per square foot. The 1977 labor cost was estimated at $0.01 per square foot.(3-2)

No data was found on the effects of the use of these materials on radon-222 concentration in mine exhaust.

Research into the use of sealants for radon-222 control is continuing. Data on the amount of funding provided for this research is not available.

Systems for Removal of Radon-222 from Air

A study conducted by A.D. Little, Inc. (3-5) for the U.S. Bureau of Mines identified several techniques which could be used in the mine to reduce radon-222 concentrations in air in the working areas. Most of the techniques presented in that report cannot be considered to have an effect on radon-222 concentration in mine exhaust air since they did not retain the radon for a period of time long enough to permit significant decay. However, three techniques were identified which retained the radon long enough so that significant decay (>90%) could occur. These techniques were 1) chemical scrubbers, 2) charcoal adsorption and 3) cryogenic condensation. The following discussion is a general summary of the techniques as described in Reference 3-5. The operational and capital costs and system dimensions are for units designed to handle flow rates of 5000 CFM. A more detailed description of the systems operating principles, design specifications, reliability and costs are presented in Reference 3-5. These systems were not considered economically feasible at the time the report was written.

Chemical Scrubber System

Investigations into the potential use of fluoride complexes to remove radon from air streams have identified several complexes that could be used to purify radon-enriched air.(3-6, 3-7, 3-8, 3-9) The conceptual system discussed in the following section is based on small scale laboratory tests. The oxidant in this scrubber system is the solid fluorine complex dioxygenyl hexafluoroantimonate (O_2SbF_6). This particular complex was selected because it has a very low vapor pressure at 25°C, releases oxygen as a gaseous reduction product, and is less corrosive than the other fluorides investigated.

In the postulated scrubber system mine air would be passed through an air filter (maximum particle size 3 um) before entering a condenser for moisture removal and cooling to 33°C. The cooled air would then enter a molecular sieve drying system for H_2O vapor removal prior to entering the radon trap. In the trap, the radon would be absorbed by the O_2SbF_6. The exhaust air, containing minor amounts of ozone (O_3), would then be passed through a bed of activated charcoal. The effluent from the charcoal would then be rehumidified before going to the work area.

The postulated system has a design efficiency for radon removal of 99%. The estimated life expectancy of the reagent, molecular sieves and the activated charcoal trap is six months.

The safety hazards associated with the system are increased gamma activity around the radon oxidant and the potential for a violent reaction of the O_2SbF_6 to any organics in the influent air. Calculations indicated that exposure levels three feet from the radon trap could be as high as 4.5 R/hr for influent flow rates of 5000 CFM of air containing 500 pCi/liter of radon.

The 1975 capital and annual operating costs were estimated to be $613,000 and $305,000 respectively. The operating costs include annual utility requirements of 832,000 kwh of electricity and 330 billion gallons of water.

It is important to note that since the time at which the A.D. Little study was prepared another fluoride complex, Hexafluoriodine (VII) Hexafluoroantimonate (V) has been identified and reportedly has the same characteristics as dioxygenyl hexafluoroantimonte.(3-10) However, conversations with one of the principal investigators have indicated that the use of these fluoride complexes is being switched from use in mine air purification systems to use as radon sampling systems.(3-11)

Activated Charcoal Adsorption

The physical adsorption of radon-222 from mine air increases as the temperature of the air decreases. The dynamic adsorption coefficient reportedly decreases from approximately 7×10^3 cm^3 (STP) air/g charcoal at 20°C to 2×10^4 cm^3 (STP) air/g charcoal at -40°C. Based on this data, a low-temperature activated charcoal adsorption system was postulated. In this conceptual design, a single bed containing 1425 lbs. of activated charcoal at a temperature of -80°C would be used to retain radon-222 for a period of 12.7 days (99% decay). As a result of radon-222 decay during the hold-up time, the discharge concentration of radon-222 would be 10% of the radon-222 adsorbed from the influent. The approximate dimensions of such a unit are 5 foot by 10 foot by 18 foot. The hazards associated with the unit are a potential increase in gamma exposure due to the accumulation of radon daughters, and a small potential for fire.

The 1975 capital and annualized operating costs for the system were estimated at $343,100 and $211,500 respectively. The operating costs include, on an annual basis, 10.0×10^6 kwh of electricity and

25 billion gallons of water. The estimated life expectancy of the unit is greater than one year.

No data were presented on disposal of residuals. However, it is estimated that disposal of the used charcoal would have to be in a facility designed to handle radioactive solid wastes.

Cyrogenic Condensation System

Removal of radon-222 from radon rich air (30 pCi/l) by use of cryogenic condensation would require liquifaction of the air followed by the selectve revaporization of oxygen and nitrogen from the liquid air. Although the dewpoint for radon at a concentration of 30 pCi/l (partial vapor pressure of 2×10^{-17} atms.) is 42.5°K and the dewpoint of air is 81°K, separation of radon and air cannot be accomplished by liquifaction of the air. This is because of the fact that at a concentration of 30 pCi Rn/liter of air, radon is dilute enough to be condensed along with the air when it liquifies. Oxygen and nitrogen could be separated from the radon-rich liquid air by selective revaporization of the oxygen and nitrogen due to the difference between their boiling points and that of radon.

In this conceptual system, mine air would pass through a filter before entering a compressor. The compressed air would then be cooled to room temperature before entering a reversible heat exchanger. The reversible heat exchanger is used to cool the compressed air to near dewpoint. The cold compressed air is admitted, in the form of fine bubbles, into a pool of previously liquified air contained in a multi-stage sparger. The radon condenses in the liquid while oxygen and nitrogen are boiled off. An alternative to the use of a sparger is to cool the air to dewpoint and to introduce the liquid air into a reboiler where the oxygen and nitrogen are boiled off and the radon remains in liquid phase. The revaporized gases, regardless of whetner a reboiler or a sparger are used, are then warmed-up and expanded before discharge. The design efficiency of this system for radon removal and retention is 99%.

The most significant hazard associated with the operation is that the liquid air could contain as much as 3.4×10^{10} pCi of radon-222 in 100 liters of air under steady state operating conditions for air containing 30 pCi/l. Rupturing of the tank containing the radon-rich liquid air could result in a rapid release of radon into the surrounding atmosphere. No data were found on estimated exposure rates near the liquid air tank.

The 1975 capital and annual operating costs of a cyrogenic system using a sparger were estimated to be $432,400 and $146,800 respectively. The annual operating costs include the cost of 1.04×10^6 kwh of electricity. The life expectancy of the system is greater than 5 years.

Bulkheads

As previously stated in Chapter II, bulkheads are routinely used by the Uranium industry to increase the effectiveness of ventilation by sealing off worked out areas. The U.S. Bureau of Mines is investigating the use of bulkheads to control radon-222 concentrations in underground mine atmospheres. In order to be effective as a mine atmosphere control, bulkheads must either be air-tight or else a bleed-off tube, connected to the exhaust airway, must be used to prevent leakage of radon-222 rich air from the closed-off area. Conversations with Bureau of Mines personnel (3-12, 3-13) and people in the industry have indicated that construction of an air-tight bulkhead is nearly impossible due to ground movement and the sudden mine atmosphere pressure changes generated during blasting operations. Until this problem can be resolved, bulkheading cannot be considered an emission control technology.

The Bureau of Mine plans to evaluate the technical and economic feasibility of using an activated charcoal trap on the bleeder pipe to reduce radon-222 emissions.(3-12)

Summary

A preliminary technical assessment of the effects of various radon-222 control technologies on radon emissions from a hypothetical 1000 ton per day mine was conducted by Bechtel National, Inc.(3-13) The study attempted to evaluate the effectiveness, costs, operation requirements and safety considerations associated with the following control technologies:

- Use of sealants on exposed or surfaces
- Systematic bulkheading
- Activated carbon absorption of Rn-222
- Mine atmosphere overpressurization
- Use of chemical oxidants as Rn sorbents

Insufficient data were found on the effectiveness and cost of overpressurization and chemical oxidants. As a result assessment was limited to sealants, bulkheads, and activated carbon. The results of the study indicated that use of an activated carbon system was the most effective and costly means of reducing Rn-222 emanation.

The report recommends further development work on sealants, bulkheads, mine pressurization and activated carbon systems.

Radon-222 Emission Controls - Uranium Milling Facilities

Review of the available literature plus conversations with mill operators indicates that at the present time, there are no research and development activities being conducted on systems to limit radon-222 emission from uranium mills (from crusher through grinding mill). However, a study on radioactive emission control systems applicable to uranium mills was conducted by Sears, et. al (3-14) and included a case study that used a radon delay trap system designed to handle a flow volume of approximately 4800 cfm. The influent air would be preheated since moisture has a deleterious effect on the ability of the activated charcoal to absorb radon-222. The air would be passed through the charcoal (approximately 2.1 x 10^6 lbs), through a second heater and a final HEPA filter. The estimated 1975 capital cost was \$3.9 x 10^6 and did not include interest and contingency funds.(3-14) No estimates of the effectiveness of the system to remove radon-222 were presented.

Advanced Emission Control Systems Applicable To Uranium Mill Tailings

The conceptual systems for control of radioactive emissions from uranium mill tailings can be classified as either physical or chemical processes. The systems classified as physical are incorporation of tailings in a solidification agent; formation of an asphaltic diffusion barrier; high temperature sintering of tailings; and selective flotation of radioelements. The chemical systems are techniques which use acids or chelating agents to leach radium from the tailings. The removal of radium-226 will therefore reduce the radon-222 flux associated with the tailings.

The conceptual techniques discussed here are systems which have been tested under laboratory conditions and/or as bench-scale models. Use of a solidification agent or formation of a diffusion barrier is considered to be nearly 100% effective in eliminating radioactive particulate emissions. Data on the effects of these systems on radon-222 emissions, their capital and material costs, and their secondary effects are presented where possible.

Physical Processes

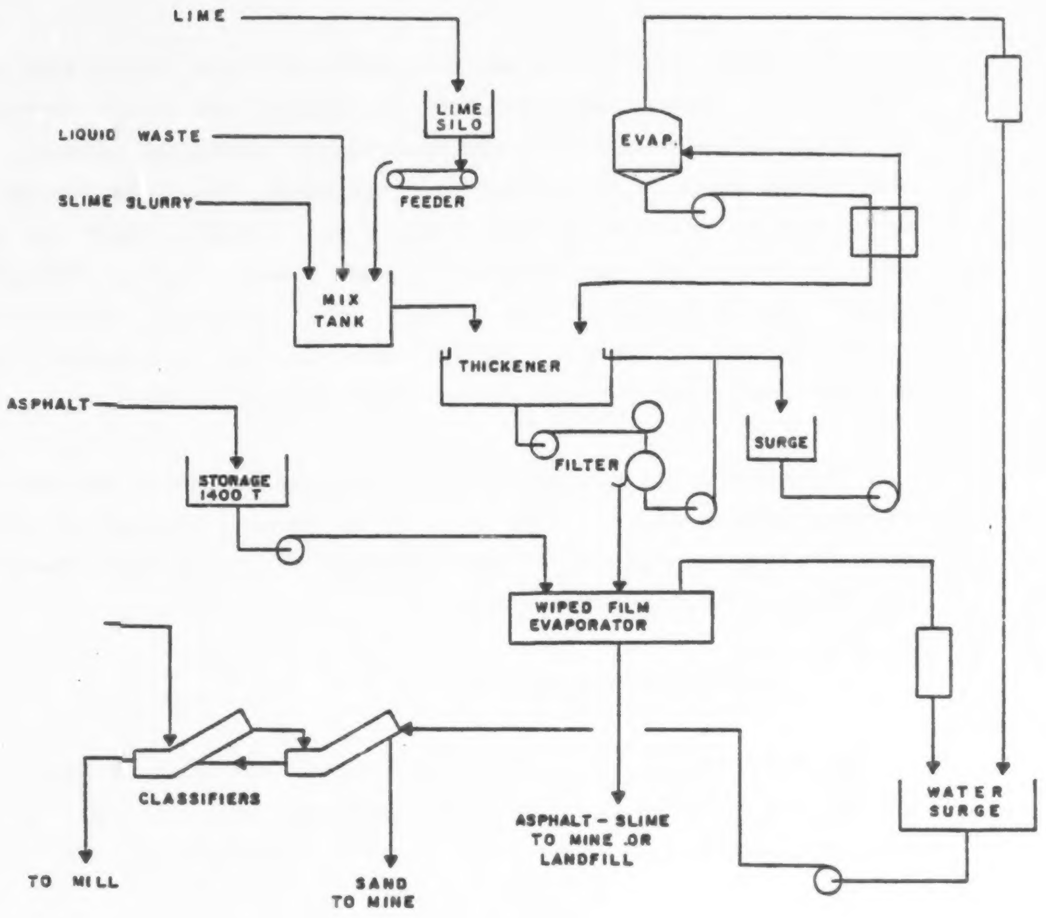
Incorporation or Fixation

The conceptual technique of incorporation involves the mixing of tailings with either asphalt or concrete to form a slurry. The slurry is either cured at the mixing facility or piped to the disposal facility prior to curing. The cured waste mixture is a cohesive mass whose physical proprerties retard radon-222 emanation and inhibit radium-226 leaching. At the disposal site, the waste mixture is buried with a cover of natural material.

Of the two incorporating agents considered, the use of asphalt as a fixating material has been examined only for the case of inactive tailings.(3-14) In this technique, the waste solutions and slimes slurry would be neutralized with slaked lime. The solids would then be dewatered in a thickener before being passed through a continuous filter. The asphalt and the filter cake would be mixed in a continuous wiped-film evaporator operated at a temperature of 160°C. The final product would be transferred to a final disposal site for burial (3-14) Figure 3.1 presents a generalized flow diagram of such a system.(3-15) The 1975 cost estimates for materials and installation are $7,100,000.(3-15) The 1975 annual operating costs have been estimated at $4,716,000.

Data on the calculated effectiveness of such a system on reducing radioactive emissions from the mill tailings have not been found.

The use of cement as an incorporating agent is based on the waste solidification procedure used at several nuclear facilities. In


LIME
LIME SILO
LIQUID WASTE
SLIME SLURRY
FEEDER
MIX TANK
EVAP.
THICKENER
ASPHALT
STORAGE 1400 T
FILTER
SURGE
WIPED FILM EVAPORATOR
CLASSIFIERS
TO MILL
SAND TO MINE
ASPHALT - SLIME TO MINE OR LANDFILL
WATER SURGE

FIXATION OF SELECTED
INACTIVE MILL WASTES IN ASPHALT

DAMES & MOORE

Source: Reference 3-15

FIGURE 3.1

this technique, wastes from an acid leach mill are neutralized with lime. Liquid wastes that have been neutralized are passed through a thickener before mixing with the neutralized sands and slimes. The neutralized waste is then mixed with concrete. The cement-waste mix would then be slurried to the disposal area.(3-14) Figure 3.2 presents a generalied flow diagram for the cement fixation technique. (3-15) The 1975 estimate of capital costs, including installation, ranged from $1,243,000 to 1,268,000, as a function of location.(3-15) No operational cost data for this process were developed.

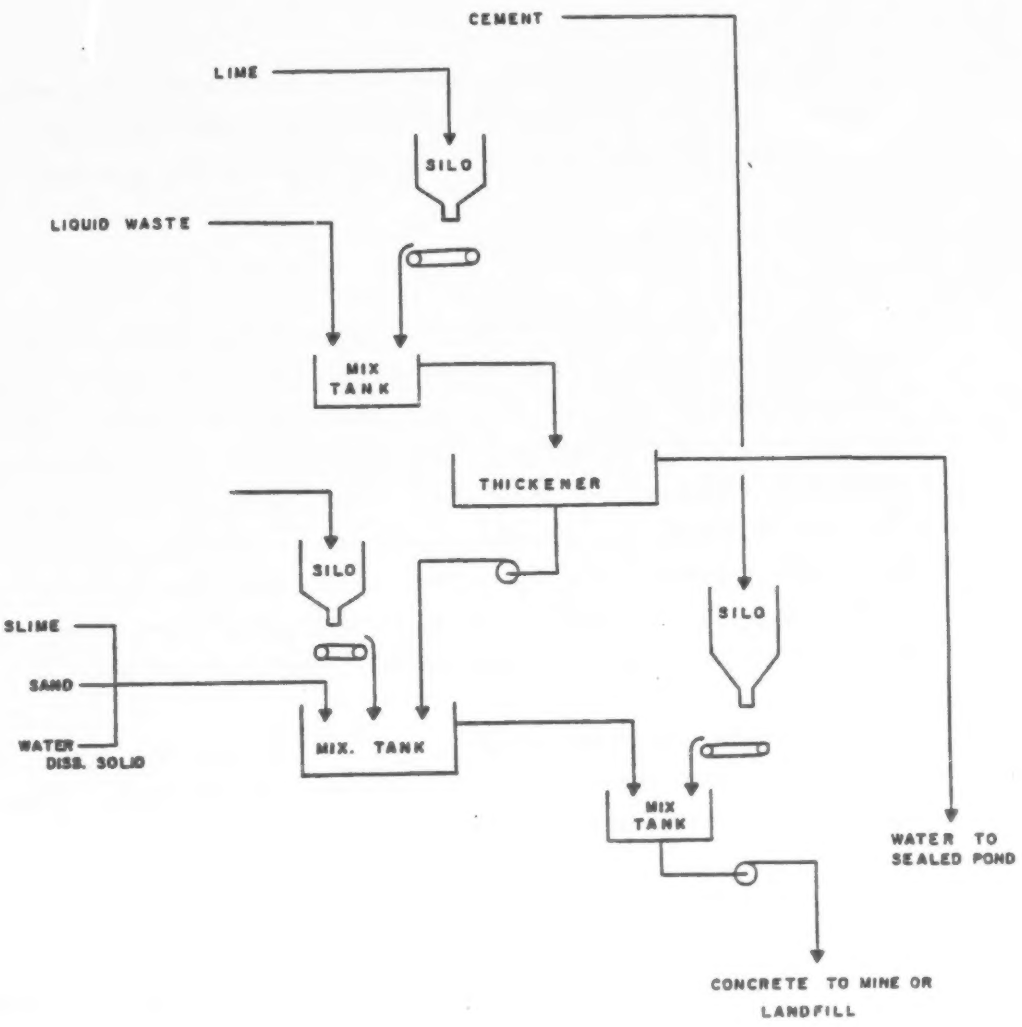
The effects of incorporating the tailings in cement are unknown. However, incorporation of the tailings in cement, followed by burial under 20 feet of earth, has been estimated to reduce radon emanation by a factor of nearly 10^3.(3-14)

Radon Diffusion Barrier

In this concept, a cationic asphaltic emulsion is spread on top of the tailings, permitted to penetrate into the tailing and cure in place and thereby form a radon diffusion barrier.(3-16)

Laboratory testing of this idea has been performed by Battelle Pacific Northwest Laboratories.(3-16) The results of these tests indicate that a 3.2 mm thick barrier of a cationic asphaltic emulsion (Armak E-63) forms an effective seal against Radon-222. These studies also indicate that the effects of radiation exposure (up to 10^5 R gamma exposure) and cyclic freeze and thaw (0° to 72°F) on the emulsion's ability to prevent radon diffusion, over the radon pressure range of 0.2 to 0.3 psi, were minimal.(3-16)

Use of the diffusion barrier technique would have to be followed by emplacement of an earthen cover over the barrier to prevent degradation of the asphalt by ultraviolet radiation, oxygen, and certain bacteria and fungi.(3-16)


CEMENT
LIME
SILO
LIQUID WASTE
MIX TANK
THICKENER
SILO
SLIME
SAND
WATER
DISS. SOLID
MIX. TANK
SILO
MIX TANK
WATER TO SEALED POND
CONCRETE TO MINE OR LANDFILL

FIXATION OF MILL TAILINGS IN CEMENT

DAMES & MOORE

Source: Reference 3-15

FIGURE 3.2

The total material and installation costs associated with this technique, as of 1975, are $0.68 per square yard for a 1/4" thick asphalt barrier for an area of approximately 153.4 acres.(3-14)

Sintering of Tailings

The process of sintering tailings was initially investigated to determine the feasibility of using high temperature (1100°C) agglomeration to reduce radium-226 leach ability.(3-17) However, the technique might result in a reduction of both radon-222 and radioactive particulate emissions. The radon-222 emanation from the tailing would be reduced because the sintered pellets would be a more cohesive mass with fewer radon diffusion pathways (e.g. stress cracks & fissures). The agglomeration of the tailings would also reduce the number of particles susceptible to wind erosion.

Currently proposed research activities are being directed, in part, towards the effects of sintering on the radon emanation characteristics of the tailings.(3-17)

Flotation

The Canadian Centre for Mineral and Energy Technology (CANMET) has been conducting a research program to develop a flotation flow sheet for concentrating pyrite, radium, thorium and uranium in the Elliot Lake tailings.(3-18) The process involves the use of highly unsaturated fatty acids, such as linoleric acid, as flotation reagents. Laboratory tests have been conducted on both active and inactive uranium mill tailings. Flotation tests on inactive tailings have produced concentrates containing approximately 75% of the radium-226 and 68% of the uranium in about 25% of the original tailings weight. Results of tests conducted on active tailings were similar; 70-75% of the radium-226 and about 60% of the uranium were concentrated in about 20-30% of the original tailings weight.(3-18).

No data on costs, energy requirements or secondary effects, were presented.

Chemical Treatment

Chemical treatment of uranium mill tailings for the purpose of controlling radioactive emission involves the use of chemical agents such as hydrochloric acid or nitric acid to remove either radium-226 or thorium-230 from the tailings. Removal of these radionuclides would lower the activity concentration of any dust emissions from the tailings, lower the radon-222 flux, and produce a low-volume waste with a higher activity concentration which could be managed more readily (i.e. buried under the lower activity tailings residue). In order to reduce the radium-226 content of the ore to the acceptable concentration of 20 picocuries per gram of tailings, more than 95% of the radium in average uranium mill tailings would have to be removed.(3-19)

The U.S. Bureau of Mines has conducted laboratory bench scale tests to determine the efficiencies of hydrochloric acid and ethylenediamine tetraacetic acid (EDTA) for removing radium-226 from alkaline or acid leach process tailings.(3-19) The altenative techniques investigated were radium removal during ore processing and removal of radium from processed tailings.

Leaching of radium from acid tailings at a 15 percent solids content for periods up to five hours resulted in 80% of the radium being leached.(3-19) Ninety-two percent of the radium was leached after tailings at 15 percent solids had been treated three consecutive times with 0.15 M* EDTA.(3-19) Leaching of alkaline process tailings (15 percent solids) with 0.15 M EDTA resulted in only 56 percent of the radium being removed.(3-19)

* M = molar solution

Laboratory test were conducted to determine the radium removal efficiency of 1.5 M hydrochloric acid on low grade uranium ores. The test results indicate that up to 98% of the radium could be dissolved.(3-19) However, the data also indicated that the presence of sulfate in the ore may inhibit the leaching of radium.

Conclusions

The primary conceptual control technologies most applicable to radon-222 emission control from uranium mines are the use of polymeric sealants and systematic bulkheads of stopes. Both of these techniques are actively being researched by the U.S. Bureau of Mines.

Review of the available literature as well as conversations with individuals in the uranium industry and government have indicated a lack of research and development work on control technologies applicable to radon emissions from uranium mills (excluding tailings).

A number of radon-222 emanation control technologies applicable to uranium mill tailings are currently under investigation. Identification of a "most promising" technique cannot be done until pilot-scale models have been developed.

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CHAPTER IV

Section 4: Future Control Technologies for Gaseous Radionuclide Releases

Introduction

Controls for manmade gaseous radioactivity that are: available, but not demonstrated; in the demonstration stage; or in the theoretical or laboratory stages, are discussed in this section by radionuclide. The radionuclides considered are tritium, carbon 14, iodine isotopes, and the noble gas isotopes of krypton and xenon. Control technologies are discussed in terms of decontamination factors (DFs) instead of by percentage of radionuclides removed, since this is the most cited efficiency terminology in the literature. A decontamination factor is the ratio of the radionuclide concentration in the gas stream in the feed to the control device to the concentration in the gas stream after the control device. Thus a DF of 1000 corresponds to 99.9 percent radionuclide removal, a DF of 100 to 99 percent removal, and a DF of 10 to 90 percent removal. Table 4-1 contains a summary of the control technologies discussed in this section.

A varying degree of emphasis is placed amongst the isotopes of concern. For perspective, the annual aggregated budgets for manmade gaseous radionuclide management programs of the Department of Energy, Division of Waste Products, is included in Table 4-2 for the fiscal years 1979-1981. (4-1) The annual budgets for the tritium, I-129 and C-14 programs are in the hundreds of thousands of dollars range, whereas the annual Kr-85 program budgets are on the order of one billion dollars.

TABLE 4-1

Future Control Technologies for Gaseous Radionuclide Releases

Radionuclide	Chemical or Physical Form	Control Technologies	Status	Comments
H-3	Gas	Combined electrolysis-catalytic-cryogenic distillation system.	Presently utilized by Ontario Hyro at Chalk River Lab scale prototype in operation at Mound Laboratory.	
	Gas	Bipolar electrolysis system.	Being developed at Oak Ridge National Labora tory. It has been tested at the laboratory scale.	
	Gas	Tritium exchange with lighter hydrogen in vanadium hydride.	The concept has been examined experimentally.	Future experimental and theoretical studies are needed for a conclusive assessment of tritium removal via cyclical processes based upon use of vanadium hydride.
C-14	Carbon Dioxide	Reaction between CO_2 and alkaline hydroxide slurries in agitated contactors or hydrated $Ba(OH)_2$ in packed beds at ambient temperature.	Bench scale studies have been performed.	Decontamination factors of 100-1000 appear feasible for gas processing with both slurries and packed beds.
	Carbon Dioxide	Reaction between CO_2 and $Ca(OH)_2$ at elevated temperatures.	Theoretical and experimental studies have been undertaken.	

TABLE 4-1 (cont'd)

Radionuclide	Chemical or Physical Form	Control Technologies	Status	Comments
I-129 & I-131		Wet scrubbers:		
	Elemental & alkyl iodides, but not aromatic iodides.	Mercuric nitrate-nitric acid method.	Laboratory tests have been performed.	Capable of decontamination factors of approximately 10,000. The system efficient for the removal of elemental iodide than for organic iodide compounds.
	Elemental & all organic iodides.	Concentrated nitric acid technique (IODOX process)	Has been sucessfully strated on a laboratory and small engineering scale using simulated off gas containing small amounts of radioactive iodine.	Capable of decontamination factors of approximately 10,000 based upon laboratory tests.
	Elemental and methyl iodines.	Inorganic adsorbents: Silver impregnated, amorphous siluric acid.	Extensive experimental work has been performed.	
		Metal impregnated alumina and alumina and oxides of aluminum and silicon oxides.	Planned for use as polishing units for iodine cleanup from gaseous effluent in two commercial fuel reprocessing plants.	Decontamination factors of 1,000-10,000 are possible for adsorption of elemental and methyl iodide by silver zeolites for fresh adsorbent maintained at 200°C.
Kr & Xe	Elemental gases.	Chemical Removal Xenon collection by chemical reaction to form a solid compound.	Early laboratory stage for Xe.	No solid or liquid reagent with sufficient oxid

TABLE 4-1 (cont'd)

Radionuclide	Chemical or Physical Form	Control Technologies	Status	Comments
	Elemental Gases	**Physical Removal Process** Selective dissolution of Kr and Xe in a flourocarbon solvent.	Pilot plant experiments have been run at the Oak Ridge Gaseous Diffusion Plant.	Possible usages lie in the processing of off gases from BWR, PWR, fuel reprocessing, and LWR accidents.
	Elemental Gases	Kr dissolution in liquid CO_2 (KALC process).	Pilot plant experiments have been run at the Oak Ridge Gaseous Diffusion Plant.	Conceived specifically for the removal of Kr from burner off gas generated in the reprocessing of HGTR fuel elements.
	Elemental Gases	Cryogenic distillation	Presently utilized at one BWR at the Idaho Chemical Plant and on a pilot scale at a German Research Facility.	The process could become operated by about 1983 for fuel reprocessing.
	Elemental Gases	Long term storage prior to release (for Kr-85).	--	Promising methods for a fuel reprocessing plant include high pressure steel cylinder and zeolitic encapsulation.

TABLE 4-2

Aggregated Budgets By Waste Management Area ($1000)

	FY 1979	FY 1980	FY 1981
Particulates	850	1095	865
Tritium	660	970	650
Monitoring	540	570	420
Process OffGas	350	405	410
Krypton-85	1050	1085	1140
Iodine-129 & Carbon-14	240	280	310
Criteria and Standards	0	200	200
Program Management	285	320	350
Routine Filter Testing	400	400	400
Totals	4375	5325	4745

A bipolar electrolysis system for tritium removal is being developed at Oak Ridge National Laboratory.(4-1) Separation of tritium from the lighter hydrogen isotopes is to be achieved by diffusion of the lighter hydrogen isotopes through metal membranes, whereas a counter-current electrolyte flow will concentrate tritium at the cell anode. The concept has been tested at the laboratory scale.

Hydrogen isotope exchange with vanadium hydride is also being examined as a possible means of tritium removal from gas streams. Tritium has been found to be more stably sorbed on vanadium hydride than the lighter hydrogen isotopes (a reverse isotopic effect).(4-2)

Carbon-14 Control Technologies

The removal of C-14 contaminated CO_2 from simulated LWR off gases by the reaction of alkaline hydroxides in both slurry and solid form at ambient temperatures has been studied as a function of both operating conditions and bench scale size. Reaction of the C-14 bearing CO_2 with the alkaline hydroxide results in the formation of C-14 bearing alkaline carbonate solids. The two most promising slurry reactants for CO_2 removal from gases of low CO_2 content are $Ca(OH)_2$ and $Ba(OH)_2$.(4-3) This conclusion is based upon CO_2 removal efficiency, reactant cost, and carbonate product stability as related to long-term storage considerations. Bench scale derived decontamination factors for CO_2 removal from gases containing 0.0337 percent CO_2 ranged from 100-2000 for a $Ca(OH)_2$ slurry (1.0m* $Ca(OH)_2$ in a 27.3 cm ID contactor, 21.0 kw/m^3 power consumption, 5-80 cm/min superficial velocities, and 15°C). These factors increase to 10^3-10^4 for $Ba(OH)_2$ slurry (0.4 m* $Ba(OH)_2$ in a 27.3 cm ID contactor, 21.0 kw/m^3 power consumption, 20-80 cm/min superficial velocities, and 15°C). Decontamination factors obtained for gases containing 1-3 percent CO_2 were approximately a factor of two lower than those for CO_2 removal from 0.033 percent CO_2 gases.

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* m = molal solution

The reaction of solid $Ba(OH)_2$ (monohydrate or octahydrate) with CO_2 at ambient temperatures is also a promising means for C-14 removal from nuclear facility off gases. The solid $Ba(OH)_2$ could be in a packed or fluidized bed. Decontamination factors of greater than 10^4 have been obtained for water-saturated air, whereas decontamination factors of greater than 10^3 have been obtained for water-saturated gas feeds containing 4.5 percent CO_2.

Kabat (4-4) has suggested the reaction of gaseous CO_2 with solid $Ca(OH)_2$ at elevated temperatures for the removal of C-14 from gas streams. Decontamination factors of greater than 10 will probably be possible for operational temperatures of 300-500°C and gas streams containing CO_2 concentrations ranging from 0.1-1000 ppm. The process has potential for use in CANDU moderator systems. A purification loop prototype will first be tested in the field.(4-4)

Iodine Isotopes Control Technologies

Advanced gaseous iodine controls can be classified as involving either wet scrubbing or adsorption on inorganic substances. Wet scrubbing techniques include mercury nitrate-nitric acid scrubbing and the concentrated nitric acid technique (IODOX process). Potential inorganic adsorbants include silver impregnated amorphous silicic acid, metal impregnated zeolites, metal impregnated alumina, and unimpregnated metal oxides. Wet scrubbing and inorganic adsorption have been proposed for both primary and secondary removal of radioiodine from fuel reprocessing plants.

Wet Scrubbers

The advanced mercuric nitrate-nitric acid scrubbing process utilizes an 8 to 10 $\underline{M}^*$ nitric acid - 0.2 to 0.4 $\underline{M}$ mercuric nitrate solution as the scrubbing agent.(4-5) Airborne iodine species are scrubbed from the gas stream and converted to a nonvolatile, soluble,

* $\underline{M}$ = molar solution

mercury-iodine complex. Elemental iodine and alkyl iodides are readily complexed by the mercury whereas the aromatic iodides are less readily complexed.(4-6)

Mercuric nitrate-nitric acid scrubbing has been demonstrated in plant installations utilizing less concentrated nitric acid and mercury solutions.(4-5) The advanced system (utilizing a more concentrated scrubbing solution) has been demonstrated on a laboratory scale. Radioiodine decontamination factors as high as 10^4 should be possible with the advanced system.(4-6) Finney, et al.(4-5) assumed a decontamination factor of 10 for radioiodine removal from reprocessing plant gaseous effluent by a mercuric nitrate-nitric acid scrubber in their study of waste treatment costs for fuel reprocessing.

The IODOX process utilizes a concentrated nitric acid solution to oxidize gaseous iodine species to a nonvolatile iodate form. All significant iodine species, both elemental and organic, are removed by the process. Iodine can be removed from the nitric acid as HIO_3, which can be converted further to a more anhydrous form for long term storage. The four basic steps in the IODOX process are (4-5):

1. Oxidation of the gaseous iodine species to nonvolatile iodate via 19-21 M nitric acid in a bubble cap or packed column.

2. Concentration of the iodine-bearing nitric acid solution in an evaporator.

3. Recycling of the iodine-free condensate from the evaporator to the plant nitric acid system.

4. Transfer of the iodine-bearing nitric acid concentrate from the bottom of the evaporator to the plant nitric acid system where it is evaporated to dryness to form a solid iodate. The second evaporator condensate is recycled to the first evaporator.

The IODOX process has potential application for liquid metal fast breeder reactor (LMFBR) fuel reprocessing plants for gas cleaning. It has been tested on a laboratory and small engineering scale with simulated off-gas containing small quantities of radioiodine. Decontamination factors of 10^4 or more have been obtained for elemental iodine and methyl iodide removal in laboratory tests.(4-5)

Solid Adsorbents

The $AgNO_3$-impregnated, amorphous silicic acid adsorber has potential application in off-gas cleaning systems of fuel reprocessing plants. Experimental work has been done on evaluating the iodine sorption efficiency, iodine loading capacity, and desorption potential at high temperatures.(4-7) Decontamination factors of greater than 10^3 should be attainable.(4-7

Silver subsitituted zeolites exhibit the highest overall bed efficiency of all metal substituted zeolites. They also have the following advantages when compared with conventional iodine adsorbents such as activated charcoal:

- o Greater iodine retention stability.
- o Nonflammable.
- o Low explosion hazard.
- o Efficient in humid conditions.
- o Resistant to poisoning.
- o The adsorbed radioiodine species form a solid insoluble product with the silver zeolite (desirable from a waste management standpoint).

Silver zeolite beds can be assumed to provide a minimum decontamination factor of 100 for I-131.(4-5) The average decontamination factor for long-lived I-129 will be lower than that for I-131. A decontamination factor of 10 has been assumed for I-129 by Finney, et al.(4-5) in their study of radioactive waste treatment costs and environmental impacts form nuclear fuel cycle waste effluents.

Silver zeolite adsorbers may possibly be utilized in only secondary and tertiary iodine treatment systems rather than primary systems due to the high cost of silver.(4-5) The usage of silver zeolites beds as polishing units for iodine cleanup from gaseous effluent is planned for two commercial fuel reprocessing plants. (4-5)

The estimated operational characteristics and adsorbent costs for the usage of solid adsorbent iodine removal systems in a 5 ton/day fuel reprocessing plant are outlined in Table 4-3.(4-6) Annual adsorbent costs of $90,000 ($110,000) and $10,800 ($13,000), respectively*, are estimated for iodine removal by primary and secondary solid adsorbent systems. Bed overloading with iodine in a primary adsorption system is expected to take place years before significant efficiency loss due to poisoning from contaminant gases in the off-gas stream.(4-6) The converse is expected for a secondary solid adsorption system.

Comparison of Wet Scrubbing and Solid Adsorption for Usage in Fuel Reprocessing Plants

Solid inorganic adsorbents offer the following advantages over wet scrubbing for iodine removal from fuel reprocessing plant off-gases:

- Solid adsorbents are comparatively non-corrosive.
- Iodine fixed to solid adsorbents is in a form that does not require further treatment prior to long-term storage.
- Solid adsorption systems are readily adaptable to remote operation.

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* Costs in brackets are in 1978 dollars.

- Long term, reliable, maintenance-free operation is expected because of the simple design of solid adsorption systems. The cost of chemicals to remove iodine in a primary iodine treatment system for a nuclear fuel reprocessing plant off-gas stream appears to be 3-5 times less for the mercuric nitrate-nitric acid method than for solid adsorbents. (4-5) It is possible, however, that the total cost of solid adsorption usage will be less than that for the mercuric nitrate-nitric acid method. If equipment installation, operational and maintenance, and storage preparation costs are taken into account, the increased flow requirements for a secondary iodine removal system appear to make the use of solid adsorbents more attractive than wet scrubbers because of the increased size and complexity of the latter treatment method. (4-5)

Krypton and Xenon Isotopes

Advanced methods for krypton and xenon removal from off gas streams can be classified as utilizing either chemical or physical processes. Chemical removal methods consist of the noble gases with a reagent such that a solid compound results. Physical removal methods consist of those removal methods that utilize the physical processes of dissolution, boiling and adsorption.

Chemical Removal Methods

Dioxygenyl hexaflourantimonate ($O_2^+SbF_6^-$), a flouronitrogen salt ($N_2F^+Sb_6^-$), and a new halogen flouride complex ($BrF_6^+AsF_6$) can oxidize xenon to form xenon salts. The reactions of xenon with these reagents are shown below.(Stein, 1974)

Research into the usage of reactions for xenon removal from nuclear facility off gas is at the early experimental stage. Laboratory tests have shown that dioxygenyl hexaflourantimonate can remove Xe-133 from air efficiently.(4-8)

No solid or liquid reagent with sufficient oxidizing power to produce krypton salts has to date been found. A stable krypton compound ($KrF^+Sb_2F_{11}^-$) can be prepared, however, by the reaction of KrF_2 with SbF_5.(4-89) Substitution of $O_2^+N_2F^+g$ and BrF_6^+ in the complex antimony salt may make possible the preparation of reagents that could combine directly with krypton to form $KrF^+Sb_2F_{11}^-$.(4-8)

Physical Removal Methods

Advanced krypton and xenon physical removal methods include dissolution in a flourocarbon solvent, dissolution in liquid carbon dioxide (krypton only), cryogenic distillation, zeolitic encapsulation, and clathrate trapping.

Pilot plant experiments have been conducted at the Oak Ridge Gaseous Diffusion Plant using flourocarbon solvents for krypton and xenon removal from off gases. Flourocarbon solvent dissolution systems for krypton and xenon consist of three functional sections: the absorber, fractionator, and stripper.(4-9) Off gas to be cleaned is contacted with the solvent in the absorber section. Most of the oxygen, nitrogen, and argon dissolved by the solvent from the off-gas are removed by the fractionator. The stripper generates the gas product (highly concentrated Kr-Xe mixtures) and a pure solvent stream for recycle back to the absorber. The pilot flourocarbon-based removal process for the Oak Ridge Gaseous Diffusion Plant is designed to achieve krypton decontamination factors of greater than 10^4 while processing a feed gas that contains typical quantities of common reprocessing plant off gas impurities, including oxygen, carbon dioxide , nitrogen oxides, water, xenon, iodine, and methyl iodide. (4-10) Flourocarbon absorbers have potential applications for BWR systems, PWR systems, fuel reprocessing plants, LMFBR vented fuel, and

LWR accident cases.(4-9) It is estimated that the process could be put into practice by about 1983 for fuel reprocessing off gas.(4-5)

Krypton removal from off gas by absorption (dissolution) in liquid carbon dioxide is known as the "KALC" process. The process exploits the fact that krypton is more soluble in liquid carbon dioxide than oxygen, nitrogen, and carbon monoxide.(4-11) It is similar in its process stages to the flourocarbon dissolution process. Absorber, fractionator, and stripper sections are present in the KALC process as in flurocarbon systems. Xenon, which is more soluble than Kr in liquid CO_2, can be allowed to concentrate in the CO_2 to the point where it is discharged from the top of the absorber, or it could be removed by a separate distillation operation on the recycle carbon dioxide stream.(4-11) The KALC process operates at approximately 20 atmospheres pressure and a temperature range of -45°C to -20°C. Initial pilot plant tests have demonstrated the feasibility of the KALC process for HTGR reprocessing plant off gases. Both absorber and process DFs on the order of 100 were obtained during pilot tests.

The cryogenic distillation process is designed to remove radioactive krypton and xenon form gaseous effluents based upon volatility differences of the gaseous constituents . Relatively pure krypton and xenon suitable for bottling in gas cylinders can be produced by the process. Cryogenic distillation is utilized commercially for isolation of the components of air, to intermittently remove radioactive krypton and xenon from a 20 scfm off gas stream at the Idaho Chemical Process Plant, and at the San Onofre 1 BWR. While the use of cryogenic distillation at the Idaho Chemical Process Plant provides a means of noble gas recovery (approximately 50%) on a semibatch basis, it does not meet the requirements of a continuous waste management system.(4-1) The Kernforschungstentrum Karlsruhe (Kfk) Research Facility has operated a pilot scale cryogenic distillation facility for over 4000 hours.(4-1) This system is being develcped for use in the Wiederaufarbeitungsanlage Karlsruhe (WAK)) reprocessing plant in which Kr and Xe are to be released for 2 hours per day. The process can probably be applied for continuous recovery, however, without major design modifications. The Japanese Tohai Mura facility plans to use cryogenic distillation. It is estimated that the cryogenic distillation process could become operational by about 1983 for fuel reprocessing plants. (4-5)

The equipment generally utilized for cryogenic distillation consists of a gas pretreatment train, regenerative heat exchanger, primary distillation column, and a batch distillation column that is used intermittenly for product purification.(4-5) The distillation column is where the cryogenic separation takes place and is operated at a temperature of approximately -300°F. Krypton and xenon tend to be dissolved and concentrated in the liquid nitrogen-argon-oxygen solution at the bottom of the column. Hydrogen (if present) and much of the nitrogen will be vaporized out at the top of the column. Water, carbon dioxide, nitrogen oxide, and hydrocarbons must be removed from the inlet gas to prevent column plugging.

Two promising methods for long term storage of Kr-85 from a fuel reprocessing plant (approximately 100 year storage for decay to provide a DF of 1000 prior to release) include high pressure steel cylinders and zeolitic encapsulation.(4-12) Storage in high pressure steel cylinders has the advantages of having had a well established history of development and use in industry, long life with good thermal and radiation resistance properties, high capacity, low cost, and ease of future recovery. It has the disadvantages of the possibility of a sudden Kr-85 release, restrictions on the purity of the gas to be stored, and possible problems associated with the accummulation of the decay product rubidium and with external erosion. Zeolitic encapsulation offers a definite safety advantage over high pressure steel cylinders, but the storage capacity is not expected to be large due to radiation damage. Clathrate trapping is probably unacceptable for Kr-85 storage because of the large costs, due to the poor thermal stability limiting the capacity.

Comparison of Chemical & Physical Methods of Krypton and Xenon Removal

Chemical methods for krypton and xenon removal may be less expensive than the KALC and cryogenic distillation physical methods since the cost of maintaining cryogenic systems is eliminated. Chemical methods are also much simpler than either of the two dissolution or cryogenic distillations methods. The physical methods are in a much more advanced stage of development and it is perhaps too early to definitively evaluate the chemical removal method.

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CHAPTER IV

Section 5: Novel Particulate Control Devices

Introduction

The control of emissions of fine particulates, approximately 3 to 5 um or less, using conventional technology has proven difficult. These fine particulates are known to be potentially hazardous to health as they are not filtered out by the human respiratory track. Existing particulate control devices exhibit problems with consistently high collection efficiencies and cost effectiveness for control of this fine particulate size range. Radioactive particulate emissions are also thought to occur mainly in association with fine particulates, so that control of respirable particulates will constitute a control of radioactive particulate emissions.

Control of fine particulates may be considered in terms of conventional technology and novel technology. Novel technologies include: relatively new control devices which have not been widely used to date; devices undergoing pilot plant studies, and; techniques in the early stages of research and development.

The three major conventional technologies for the control of the fine particulate emissions are electrostatic precipitation, wet scrubbing, and fabric filtration. Bag filters are probably the most effective present technology for filtration of fine particles, but have significant drawbacks due to their limited face velocity, high pressure drops, limited capacity for loading and tolerance to corrosive environments, and high maintenance costs. Consequently, for a high volume gas discharge the filter area required is very large, producing high capital and operating costs. In electrostatic precipitation the cost/benefit ratio increases significantly with decreasing particle size and increasing particle resistivity. A similar situation exists for wet scrubbing devices since high collection efficiency for submicron size particles is achieved at the expense of extremely high pressure drops and at corresponding high costs.

Current research is aimed at evaluating viable alternatives to conventional technologies and improving the effectiveness of existing techniques. The goal is to find methods of improving the fine particulate collection efficiency and reducing the capital and operating costs of fine particulate emission control.

The purpose of this section is to identify and compare the technologies being developed for fine particulate control with particular emphasis on novel technologies.

Criteria for Inclusion in the Study

There has been much data published on particulate control devices and on modifications of existing conventional control techniques. This information is readily available in the literature. For this portion of the report, efforts have been limited to the study of advanced systems, i.e., those systems which are not commercially available and those techniques or devices which are still under development. Data and information on these systems are not fully accessible. The objective is to summarize the research, much of which is in its early stages. The criteria used to include various research in our study are discussed below.

Respirable Particulates

Since the particulate matter of most concern from the point of view of human health is primarily in the respirable size range, our study has been limited to the study of collection devices which are effective for that range ($\leq$3 um aerodynamic diameter).

Advanced Technology

Data on conventional collection systems (baghouses, ESPs, scrubbers) are plentiful. This section will address what is considered to be advanced (developmental) systems. Admittedly, the distinction between advanced or "novel" and conventional is somewhat arbitrary. The catalogue in the appendix, however, does contain information on conventional systems which was incidentaly gathered while addressing advanced systems information.

Possible Application on a Wide Scale

The concepts and technologies studied have been limited to those systems which might one day be applicable on a wide-scale in industry for fine particulate control.

Application to Specific Industries

Where possible, research has been limited to those controls which might be applicable to the copper or phosphorous industries or to fossil fuel plants, although some devices are in such early developmental stages that their application to those industries is uncertain.

Point Source Emissions

The study has also been limited to emissions from vents, stacks, or other point sources. Fugitive emissions are not covered in this report.

Summary of Results

The information collected for the examination of advanced technologies was obtained by a literature search and personal contact with researchers in the field of fine particle control. Researchers who were contacted were also asked for the names of others who were active in the study of fine particle control.

Approximately 70 individuals in 40 different research and industrial centers were personally contacted regarding the current research in fine particulate control. In addition to the personal contacts, approximately 40 references were consulted. Included in the search were governmental agencies, universities, control equipment manufacturers, research institutes, utilities, and industrial users of control equipment. Also consulted for data were the Smithsonian Scientific Index, the index issues of the Journal of the Air Pollution Control Association, Technology Profile Reports of the U.S. Patent Office, EPRI lists of current research, and NTIS abstracts. A summary was made of each research effort identified and is included in Appendix III.C as a research catalogue.

A summary of the results of our study is given in the Summary of Conclusions in Table 5-1.

In essence, it is believed that all the novel technologies summarized in Table 5-1 could be useful for a given emission source for which conventional control is inadequate. It is recommended that each advanced system be considered when such a situation arises. In general, the electrified filter bed (EFB) appears to have undergone the most extensive commercial application testing and is probably the technique most ready for wide-spread use.

It also became apparent from the study that, in general, the major emphasis on research in this field at present has shifted from the study of truly novel devices to the improvement of conventional systems which show great promise for fine particle control, with some modification such as the combinations of particle charging and electrostatic precipitation, electrostatics and fabric filtration, electrostatics and scrubbing, and electrostatics and cyclonic collection.

TABLE 5-1

Advanced Technology Comparison

	Electrified Beds					
	EFB	**Filter Beds**	**Sonic Agglomeration**	**Magnetic Separation**	**Foam Scrubbing**	**Novel ESP**
Effectiveness (for particles with MMD ≤3 m)	Oil - 80-90% Asphalt - 93-99% Coal - 99%	90-99%	Depends upon efficiency of coupled collection system. Increase particle diameter by 2-7 times.	90-99%	90-99%	Fluid electrode WWEU >90% TEP 99.9%
Energy	1 hp/1000 cfm (fan) + 100 watts/10,000 cfm (charger)	N/A*	5 to 20 hp/1000 cfm in addition to collection system	1.4 hp/1000 cfm	Operating cost $4.5 acfm	WWEU 500 watts/1000 cfm Others not available
Cost	$50,000/20,000 cfm	N/A	N/A	$3.14/cfm flange-to-flange)	$200,000/$10^5$ acfm	N/A
Residuals	Bed media Collected particles	Filter media Collected particles	Depends upon collection system	Dry particulate	Liquid waste	FE Liquid waste WWEU Liquid waste TEP Dry particulate
Applications	Asphalt Oil Coal Fluidized bed combustion Copper High temperatures Mineral recovery High resistivity ash	Reverberatory furance. Most applications for conventional filters. High resistivity ash.	Special applications for toxic substances. Add on to existing collection systems especially for wet scrubbing systems.	Iron and steel industry. Ferralloy industry	Not anticipated as yet	FE Textile industry WWEU Future applications in industry where continuous cleaning is desired TEP Where ESPs are employed

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* N/A Not Available.

EPA's own research has also recently shifted from the identification of novel devices to the development of those that have showed promise, and to such fields as the control of fugitive dust, the development of measurement techniques for respirable particulates, and the development of a respirable particulate standard.

Description of Technologies

This section describes the technologies studied and the variations on those technologies. Possible applications for each class of fine particulate control process are also addressed.

Electrified Beds

Filtration by granular filters has been used since the nineteenth century. This technique has recently been modified by the application of electric fields in attempts to increase the collection efficiency by reducing the required particulate residence time for collection. High collection efficiencies for fine particulates have been demonstrated in laboratory and pilot scale experiments, and full-scale tests are now being planned. The basic advantages of the technique are its applicability to high temperature and corrosive emissions and its potential as a fine particle collection mechanism which requires less space than electrostatic precipitation or cloth bag filtration. Potential disadvantages are re-entrainment of collected particulates and bed material and degradation of performance with bed aging.(5-1)

General Bed Filtration Description

The mechanisms responsible for particulate collection in a non-electrified bed are inertial impaction, direct interception, Brownian diffusion, and sedimentation. Sedimentation significantly influences only the collection of large particulates and therefore is not important to our discussion of fine particulates. Particle inertia is a major influence for particles of 1 micron or greater in diameter, and direct interception is considered a major factor in the collection of particles of 0.2 to 1 micron. Very fine particulates of approximately 0.2 microns or less in diameter are thought to be mainly removed from the gas stream by Brownian motion. The interaction of these collection mechanisms has not been entirely quantifiable, but various empirical and theoretical equations have been developed which give fairly good agreement with experimental results. The applicability of the various collection mechanisms to a particular aerosol depend upon the size distribution of the aerosol, the velocity and density of the particles with respect to the transport medium, and the susceptibility of the particles to external applied forces such as, for example, electric or magnetic fields, thermal gradients, or sonic energy.(5-2, 5-3) If an external field is applied, the collection efficiency may be increased due to the greater attraction of the filter media for the particles caused by the external field. The greater attraction allows shorter residence times for collection and a corresponding reduction in bed size.

Specific Electrified Bed Technologies

The electrified filter bed (EFB) consists of a bed of granular particles which are either in a fixed or movable mode (Figure 5.1).

The fluidized filter bed is one kind of EFB*. Fluidization can increase the surface area available for collection and thereby aid in maximizing collection efficiency. However, fluidization can also cause operational problems and increased operational expense. Due to the large collection surface area, residence times for collection are greatly reduced. The incoming particulates are generally charged by ion impact prior to entering the collection stages of the EFB. A pre-filter is also used to collect the larger particles through inertia and impaction. An electrical field is applied across the bed and the induced charges on the semi-insulating bed particles attract the particles of the incoming gas stream. Screens are often introduced into the collection column to prevent non-uniformity in the gas-solid distribution ("bubbling") in a fluidized bed. Both the

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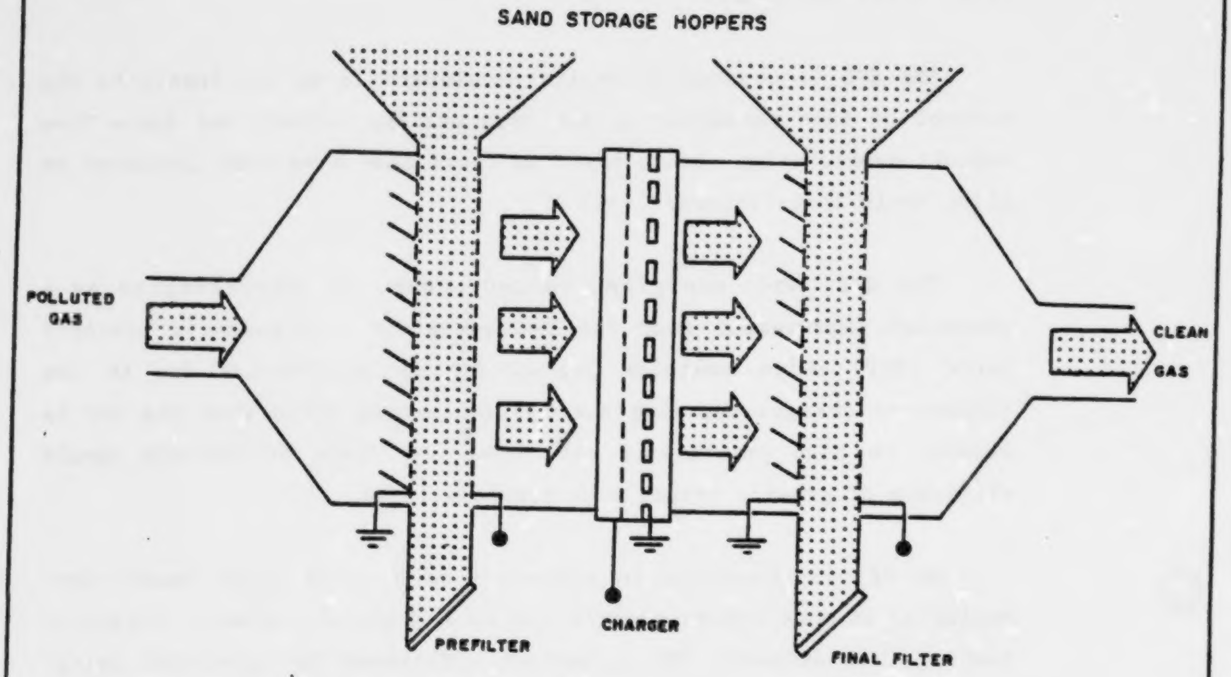
* The bed is "fluidized" if lifted and balanced against gravity by the upward motion of a gas.


SAND STORAGE HOPPERS
POLLUTED GAS
CLEAN GAS
CHARGER
PREFILTER
FINAL FILTER

SCHEMATIC OF THE ELECTRIFIED BED TECHNOLOGY

Source: Reference 5-1

DAMES & MOORE

FIGURE 5.1

charging and collection sections of the EFB can be energized from common A-C, 60 Hertz power or by DC. Typical bed particles are sand, clay, glass and slate.

The EFB is considered by its developers to be applicable to the control of fine particles of ash from utility boilers and fumes from asphalt reprocessing plants based on tests that have been conducted on pilot scale installations.(5-4)

The EFB, when energized by A-C power, is considered to be a potential improvement over the D-C energized electrostatic precipitator (ESP) which exhibits degradation in performance due to the buildup of charges opposing the ESP collecting field when the ESP is exposed to high resistivity ash. The A-C field of the EFB should eliminate or greatly reduce such problems.(5-5)

An EFB is presently in operation on a pilot plant fossil fuel boiler at an auto manufacturer's facility, and, in the early stages of testing, has achieved 99% collection efficiency for submicron particles. A full-scale test of an EFB is now underway at an asphalt facility. No data has been reported to date, but the unit is designed for a 20,000 CFM gas flow.(5-6)

Dietz (5-7) is currently working on an internally-funded project at General Electric to develop electrified bed filters for protection of gas turbine engines at 1700-1800°F. He is utilizing image charging of the bed particles instead of an applied field in an attempt to cut energy usage. Particle collection data should be available in 1980.

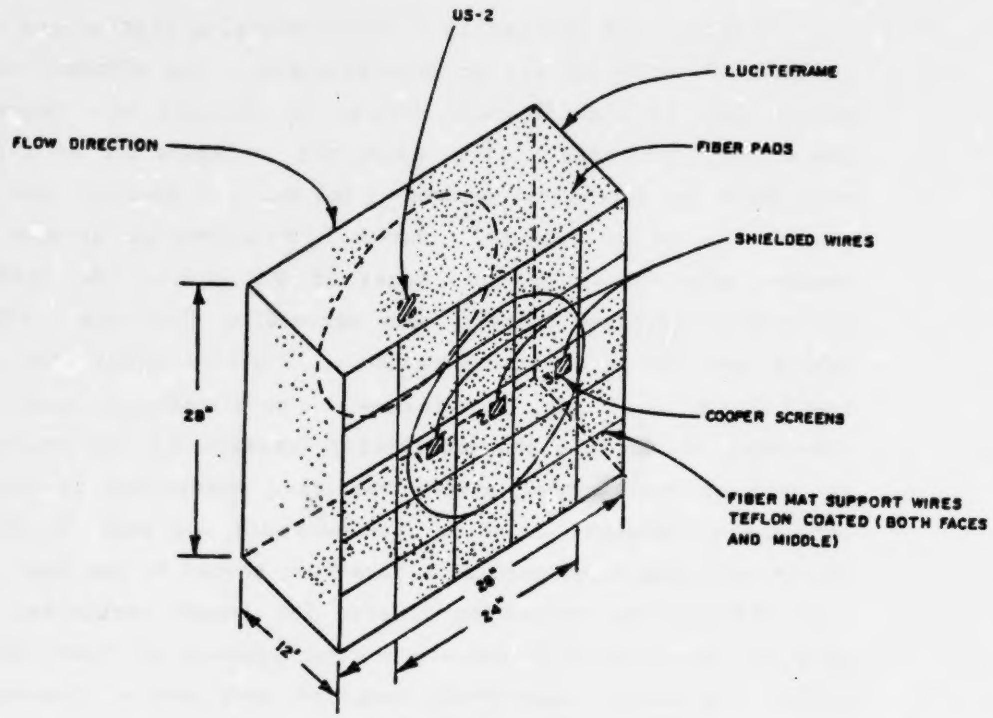
Electrostatic Capture in Fiber Beds

This collection technique utilizes electrostatic augmentation of a non-conducting non-fluid bed of fibers. The electric field is induced in the bed by molecular ion or charged particle deposition.

A schematic of the fiber bed and the charging section are shown in Figures 5.2 and 5.3.

Particles are charged in a corona-charging section and collected in beds of teflon fibers or polypropylene. The effiency of conventional ESPs is significantly reduced as particle size decreases and resistivity increases. Tests using one configuration of a fiber bed were made on particles between 0.06 and 0.7 microns and with resistivities of 10^5 to 10^{12} ohm-cm. Efficiencies greater than 90 percent were found for flow rates of 300 ft/min (24" diam. pipe). Efficiency increased linearly with decreasing flow rate (99% for 100 ft/min and 100 mg/m^3 concentration). Pressure drops were generally low (<1 in. H_2O, avg. 0.5 inches. For industrial applications, knowledge of particle characteristics (resistivity and concentration) as well as the control system operating conditions is required to optimize efficiency, cleaning frequency and the area of filter bed. Though only submicron particles have been tested it has been suggested that efficiencies should be greater for larger particles. Current work in improving high temperature performance of fiber filters may extend the useful temperature range of this control technique.(5-8)

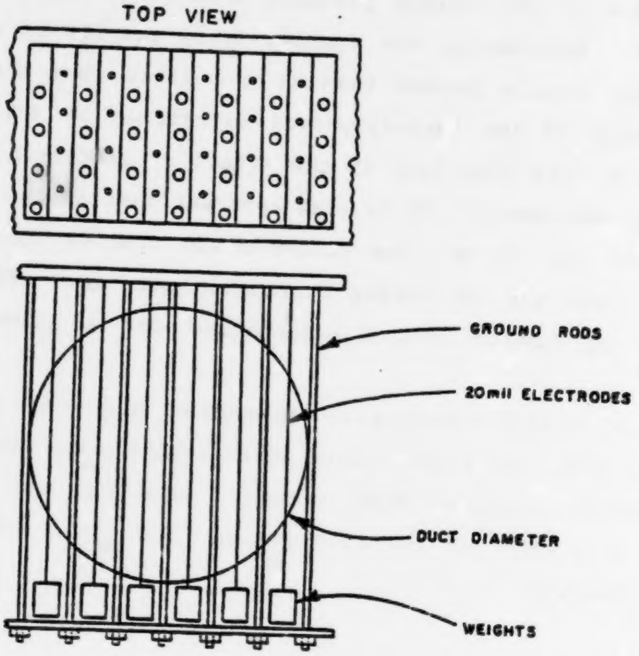
Current research being sponsored by the U.S. Environmental Protection Agency and by private industry indicates that the collection efficiency of electrostatically augmented filters may be increased from 99.5% to 99.9% with a concurrent reduction in pressure drop.(5-9, 5-10) Although this efficiency improvement is a relatively small percentage gain it could be quite significant if applied to reducing emissions of highly toxic substances. Research is also being conducted at this time into increasing the operational time of filters and filter beds through an understanding of basic filtration mechanisms. Such an improvement would make these units more cost effective due to the less frequent cleaning and disposal requirements. Some of this work is at present unfunded (5-11, 5-12) while other research is funded by the Environmental Protection Agency and by the Department of


US-2
LUCITEFRAME
FLOW DIRECTION
FIBER PADS
SHIELDED WIRES
COOPER SCREENS
FIBER MAT SUPPORT WIRES TEFLON COATED (BOTH FACES AND MIDDLE)
28"
1
2
3
28"
24"
12"

FIBER BED SCHEMATIC

Source: Reference 5-8

FIGURE 5.2


TOP VIEW
GROUND RODS
20mil ELECTRODES
DUCT DIAMETER
WEIGHTS

SCHEMATIC CHARGE SECTION WITHOUT CAN

FIGURE 5.3

Energy. Current research (5-13) has also identified that electrostatically augmented filters can be reduced in size by a factor of four due to the reduced pressure drop which occurs with such augmentation. Apparently, the applied field results in a deposition which is more loosely packed than if the field were absent, although the mechanism of the loosely-packed deposition is not completely understood at this time (nor is the affect of different dust resistivities on the phenomenon). It is also apparent that instead of decreasing the size of the filter, the filter could also be operated for a longer time, thus perhaps making filtration more cost-effective compared to other applicable control techniques for a given emission source.

An electrostatically augmented baghouse has been operated at a 1000 CFM pilot plant installation capturing asphalt, gypsum, phosphate, electric steel furnace, asbestos, and cement particulates with very high air to cloth ratios (8.0 - 15.0 CFM/sq. ft.) and high efficiencies.(5-14)

Agglomeration Techniques

Since the collection of respirable particulates is the most difficult and most energy consuming of all industrial particulate emissions, research efforts have been directed towards developing systems that can improve the effectiveness of conventional control devices in capturing fine particles. One method is to cause agglomeration or growth of fine particles in order to simplify removal by existing controls. Several methods have been suggested to precondition particle-laden gases. All are basically means by which the mean size of the particles is increased and the number density is decreased. Changing the particle size distribution in this manner could produce an increase in efficiency of a downstream collector and could lead to a reduction in overall cost since collection devices generally retain a greater mass of a given aerosol as particle size is increased.

Mechanisms that have been suggested as possible agglomeration inducers are thermal, turbulent, magnetic, and acoustic. Recent studies have been made investigating the practicality of these methods.

Thermal Agglomeration

When particles come into contact with each other and agglomerate, strictly as a result of a thermal gradient, the process is termed thermal agglomeration. An evaluation of this process as a pre-conditioning method for fine particle control indicates that the overriding disadvantage of thermal agglomeration is the long residence time required to achieve significant particle growth.(5-15) Typical increases in size by a factor of two to three required on the order of one hundred minutes. An analysis of methods which might enhance the rate of thermal agglomeration indicates that they are impractical or will not reduce residence times to those required for industrial applications (seconds or milliseconds). Therefore the process is not a viable approach for augmenting the ability of present control technology to collect fine particulate emissions, unless a high-thermal gradient already exists in the process gas and that gradient is applicable to enhancement of conventional control device efficiency.

Turbulence

A study of agglomeration through application of turbulence indicated that agglomeration of fine particles decreases as particle size decreases.(5-16) Turbulence does not significantly increase agglomeration of particles less than 0.2 um in diameter and although agglomeration of particles greater than 0.5 um in diameter can be shown to be important, the energy expended to achieve the increase is on the order of 40 hp/1000 ft^3. This is high, and if an external source is required to provide turbulence, then turbulent agglomeration

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is not very attractive. Also, residence times on the order of one minute are neeeded to increase a 0.5 um size particle to 2 or 3 um. In essence, inducing turbulence to enhance particle agglomeration is not very useful. If turbulence occurs naturally and is not detrimental to the main control system (turbulence often degrades ESP performance), then it could be used to achieve some agglomeration and better collection characteristics.

Magnetics

The use of magnetics as a means to produce particle agglomeration has also been investigated.(5-17) Calculations indicate that agglomeration through the use of magnetic forces is impractical due to the long residence times required (up to 1000 sec. for concentrations of 2 to 23 g/m^3), the potentially large magnetic field system required if shorter residence times were attempted, and the necessity of using a particle-charging system to prevent repulsion of uni-polar particles. Researchers believe that the direct capture of fine particulates should be readily achievable in magnetic separators, provided the particles are ferromagnetic in nature. Research in the field of high-gradient magnetic separation is still ongoing and will be addressed later in this report.

Acoustic Agglomeration

Of the agglomeration techniques being studied, the use of acoustics to condition fine particulate matter is probably the most contraversal. Much research is still being done in this area and opinions vary as to how cost effective the approach may be. The basic theory of sonic agglomeration centers around the fact that when acoustic waves are introduced into an aerosol, fine particles are caused to vibrate at a much greater amplitude than that of the coarser particles. Given sufficient amplitude, the fine particles will collide with the coarser ones and agglomerate.

A study by Midwest Research Institute (5-18) concluded that the utility of a sonic agglomerator as an aid to controlling fine particles seems doubtful. Although increased collection efficiencies were demonstrated by a downstream cyclone, energy requirements ranged from 5 to 20 hp/1000 cfm. It was found that sound intensities on the order of 160 dB were necessary, creating a muffling problem that could be important, and that to obtain maximum agglomeration an optimum sound frequency was required for different particle size distributions.

A study for EPRI (5-19) reached similar conclusions but found that for industrial applications the agglomeration rate is relatively independent of the sonic frequency when hydrodynamic interaction (induced by water spray) is the predominant agglomerator for particle diameters greater than 1 um. This suggests the possibility of using frequencies of the order of a few hundred cycles per second for effective dust control in industry, which should increase efficiency in sound generation and eliminate the need for finding an optimum frequency. Further work in practical design and hardware development in this technology was suggested.

Supporters of acoustic agglomerators feel the technique can be economically competitive for special applications in which conventional devices are not effective. In a paper by Shaw and Wegrzyn (4-20) it is emphasized that sonic agglomerators cannot compete in applications where the conventional devices already have been successfully used. However, the sonic agglomerators have some characteristics which make them uniquely suitable for certain special applications, such as the suppression of radioactive sodium-fire aerosol in hypothetical Liquid Metal Fast Breeder (LMFBR) accidents, and the control of particulate emission under special conditions where conventional abatement techniques are not applicable. For example, in a recent report on LMFBR accidents (5-21) 24 different air cleaning systems were investigated. Of these, acoustic agglomeration is rated to be number one in terms of effectiveness and fourth in terms of fabrication. If research and development effort can improve the credibility, reliability, and compatibility of acoustic agglomeration, it may be one of the best choices for this emergency use. Shaw (5-22) is also currently investigating other applications in which it might be feasible to employ sonic agglomeration, such as using sonics as a pre-conditioner for EFBs and for cyclones. He is studying the sound frequency problem and believes that his work will indicate that the sound frequency does not have to be increased as agglomeration progresses.

Studies performed at the Ontario Research Foundation (5-23, 5-24) and the University of Toronto have examined different approaches to acoustic conditioning. The following two complimentary principles were explored.

(i) First, the conventional standing sinusoidal acoustic field, used in essentially all earlier acoustic dust conditioning work, was dropped in favor of progressive saw-tooth fields. This change in acoustic configuration allowed major simplifications in the agglomeration chamber yielding both capital and operating cost savings.

(ii) Second, the normal techniques of sound generation - such as sirens and mechanically activated pistons - were discarded in favor of a resonant pulse-jet acoustic source. This not only allowed a direct conversion of fuel to sound and the use of a simple no-moving-part device, but also readily produced high intensity progressive saw-tooth acoustic fields.

The results of this research/development program are thoroughly reviewed in reference 5-23. In summary, the practical results of this program showed that significant improvements can likely be achieved by this process in all three areas of capital, maintenance, and operating costs. At the same time, the mean particle size was increased 5-7 fold.

Scott (5-24) suggests that wet scrubbers are perhaps the most promising of the collector systems for use in his approach to acoustic conditioning of fine particles. As an example, he sites that a venturi scrubber used 3,150 bhp to collect 90% of 0.2 um particles while only 60 bhp was required to collect 90% of the 0.5 um particles, the implication being that by affecting a 2.5 fold increase in mean particle size a 50 fold reduction in scrubber power requirements would be realized. Scott also cites other possible applications in high pressure-temperature applications, such as fluidized-bed coal combustors. Mechanical or inertial separation by cyclones seems to be one of the few existing systems that can operate at the anticipated temperatures and pressures of these combustors. However, the collection efficiency of cyclones is not sufficient to meet gas cleanliness standards set by turbine manufacturers. Initial investigations point out that if the size distribution of particulate matter entering the cyclone is increased by a factor of 5, the efficiency of the cyclone would be improved enough to meet the turbine inlet standards. It is hoped that scaling of current designs of acoustic/cyclone systems might meet this inlet criteria. Further work needs to be done in this field.

Other Agglomeration Techniques

A study has recently begun at Stanford University to determine the feasibility of agglomeration through the application of A-C electric fields.(5-25) The study is being funded by EPRI and is based on the anticipation that the differences in particle motion caused by size differences will produce useful agglomeration. The Air Pollution Technical Institute has also begun work on a "particle-by-particle scrubber" which uses electrostatic forces to agglomerate the fines with 100 um collector particles. This work is currently in the pilot stage and is designed for a total collection efficiency of 95% for 1 um particles when combined with conventional collection techniques. (5-26)

Magnetic Separation

High gradient magnetic separation (HGMS) is a particularly novel approach to collection of particulate emissions from industrial sources. In the last decade, research and commercial applications have demonstrated that HGMS is an effective and economical method of removing small paramagnetic particles from selected liquid streams. In particular, HGMS has achieved commerical acceptance in the kaolin clay industry as a wet beneficiation process. Research into the potential success of HGMS in removing fine paramagnetic particles from gas streams is still ongoing. Much of the work in the field has been done by Gooding, et al.(5-27)

The basic system consists of a canister packed with fibers of ferromagnetic material (such as stainless steel wool) which is subjected to a strong external magnetic field. Strong magnetic forces near the edges of the fibers result in very efficient collection of fine paramagnetic particles, thereby cleaning the particle-laden gas as it passes through the cannister. When the fiber matrix becomes loaded, the field is removed and the particles may be flushed from the cannister. The process is essentially enhanced filtration; however the void volume is typically much larger than in a conventional filter allowing high fluid velocities with relatively low pressure drops. The high through-put suggests smaller space requirements than for electrostatic precipitators or baghouses. Also, the stainless steel wool is a common, relatively inexpenisve material which is resistent to high temperature and corrosive environments. The lack of any sparking mechanism should make the process amenable to dry, combustible environments, assuming proper design precautions.

Theoretical, bench-scale and pilot scale research has been carried out with dust from a basic oxygen furnace and an electric arc furnace. To be effective the particles must have a relatively high magnetic susceptibility, thus applications may exist in the iron and steel industry and the ferroalloy industry. Results of testing show that efficiencies greater than 99% are obtained for particles greater than 1 um in diameter and greater than 90% for submicron particles.

A preliminary economic analysis indicates that the process may be competitive with conventional controls. Operating costs are projected to be much less than that of wet scrubbers and less than electrostatic precipitators, although capital costs may be somewhat higher. The economic viability of the process may depend upon the development of cyclical cleaning or continuous operation systems (which have been demonstrated for liquid systems).

Though the HGMS process is currently restricted to particles of high magnetic susceptibility, the possibility exists that the process stream can be seeded with a magnetic material that will become physically or chemically associated with suspended particulates. This conversion of non-magnetic material to strongly magnetic forms is suggested by Oden, (5-28) e.g., magnetic desulfurization schemes for dry coal. It also appears that magnetics may play a useful role in the cleaning of coal before burning.

Foam Scrubbing

An investigation of the application of foam scrubbing for fine particulate control has been made by Monsanto Research Corporation. (5-29, 5-30) In this process, diffusion and sedimentation appear to be the primary mechanisms of particle collection. Theoretical calculations were verified by bench-scale experimentation (2.5 acfm) and a small pilot scale demonstration (500 acfm).

The basic operation of the device entails forcing the gas stream contaminated with particulate matter through a screen wetted with a surfactant (surface active) solution. As the gas passes through the wet screen openings, foam is generated and the gas is enclosed in a multitude of small bubbles. The distance which a particle must travel to reach a collection surface is greatly reduced by the bubble enclosure. The foam passes through a main chamber of the scrubber where the particulates are given time to migrate and collide with the bubble wall. As the foam is broken, particles retained on the bubble walls are collected in the foaming liquid.

Theory indicates that bubble diameter and residence times are of primary importance in collection efficiency. In the bench-scale experiments collection efficiencies for submicron particles were seen to asymptotically approach 100% as the residence time increased. Efficiencies were typically greater than 90% for 80 second residence times. A bubble size of 0.8 um was used in the bench tests. Pilot scale tests showed lower efficiencies due to the shorter residence times (20 seconds) and larger bubbles used (3.9 mm).

An estimation of capital and operating costs was made which indicated competitiveness with conventional control devices. The costs, however, are highly dependent upon residence time. Residence times of 40 to 60 seconds are suggested to obtain collection efficiencies of 90%. Calculations made by George Lamb (5-31) seem to indicate that, in order to obtain 99% collection efficiencies, 0.25 mm size bubbles and residence times of 100 seconds are needed. That would imply much higher costs. These residence times may be impractical in industrial applications. Residence times could be reduced with smaller bubble sizes, but at the expense of greater pressure drops needed to make the bubbles.

Novel Electrostatic Precipitation Devices

High resistivity dust is normally the major problem in electrostatic precipitation. In order to obviate this disadvantage, Penney and Gelfand have proposed a device called the Trielectrode Electrostatic Precipitator (TEP).(5-32) The TEP is based on the concept that the layer of collected dust behaves like capacitance and resistance in parallel so that the corona will occur in short pulses and yet maintain a moderately constant current through the dust layer. Following each pulse the voltage through the dust layer will decay exponentially with a time constant varying with the resistivity of the dust. For a resistivity of 10^{12} ohm-cm the time constant is about 0.2 seconds. Therefore, if the pulses of corona occur every 0.1 seconds, the voltage across the dust layer can be moderately constant. During the period between corona pulses, a third electrode is kept at a high potential so as to provide a very strong field to drive the charged particles toward and deposit them on the collecting electrode. During the corona pulse, the third electrode should be at a relatively low potential so as not to disturb the normal distribution of corona current.

A one-half scale laboratory test was conducted to compare a conventional electrostatic precipitator and the TEP. The resistivity of the dust was controlled by varying the humidity in the room. Test dust was supplied by a fluidized bed feeder with a cyclone used to remove larger particles. Results have shown that the TEP is essentially insensitive to particulate resistivity up to 10^{13} ohm-cm and can give a consistently high collection efficiency regardless of the type of coal burned in a utility application. A comparison of the two precipitators shows equal efficiency for 1×10^{10} ohm-cm dust, but for dust with a resisitivity of 1×10^{12} ohm-cm the regular precipitator efficiency was only 50% while the collection efficiency of the TEP was about 95%.

Another novel electrostatic precipitator device is being developed by Albert Baril (5-33) for the textile industry. Called a fluid electrode precipitator (FEP), it was designed in an attempt to alleviate problems which arise in the cleaning of conventional precipitators. Built for continuous operation, the FEP is a conventional precipitator in which the collecting plates are replaced by columns of falling water. The dust-laden air passes through a corona field generated between charged wires and grounded columns of water. Dust particles are charged and precipitated directly on the flowing water columns. The falling columns of grounded water act as cylinders in cross flow and create vortices for enhanced particle collection. Auxillary electrodes and discharge electrodes can be positioned in arrays to direct charged dust into the grounded fluid. The water flows into a collecting tank and the clean air passes into an exit duct.

The fluid is deflected very little by drag forces at velocities up to 100 ft/min. Fluid is deflected by electrostatic attraction, but this can be compensated for by auxiliary electrode placement. A prototype unit was tested on cotton dust (3.6 um mean mass diameter) with flows of 250 to 500 ft/min. Units of a more practical size would require intermediate flow tubes at approximately one foot intervals of vertical fall to catch the fluid, decelerate it, and return it to laminar conditions. Mass efficiencies ranging from 78 to 93% were obtained which varied with flow and field strength parameters.

The developers feel that once properly adjusted, an array of fluid electrodes can operate with low maintenance to continuously remove dust. The basic concept lends itself to a modular design in which the volume of air being processed could be increased by simply stacking several units. Further research is being conducted to apply findings to large prototype units, to increase efficiencies with deeper or more optimally selected electrode arrays, and to extend the principle to other industrial situations requiring continuous fine dust collection.

A device which combines inertial and electrostatic precipitating mechanisms and features continual washing of the collection surface, is being developed by Robert Reif.(5-34) Also designed and tested with the textile industry in mind, the system, called a wet-wall electroinertial unit (WWEU) consists of a concentric wire-in-tube precipitator. The charging wire is located axially in a stainless steel tube in a vertical orientation. Air enters tangentially at the upper end of the tube (through a duct with a flattened cross section) and acquires a rotating movement. When high voltage is applied to the wire, an ionizing corona charges the dust in the air. As the air flows through the tube, the charged dust is driven to the wall by the radial electrical field.

Water from an inlet at the upper end of the tube flows down the wall and flushes the precipitated dust into the water outlet at the lower end of the tube. The rotational movement of the air also induces rotational flow in the water, which assists in uniformly wetting the surface of the tube. Clean air is expelled from the tube's lower end.

The WWEU has been tested on cotton dust with mass median diameters of about 0.3 to 4.0 um with flows of 100 to 800 cfm. Total mass efficiencies were observed to be in the 96 to 99 percent range, using a fine atmospheric dust for the test aerosol. The efficiency dropped considerably when the flow rate was increased and particle size decreased. The energy consumption was reported to be fairly high (on the order of 500 watts/cfm) but the advantages of continuous operation and self-cleaning combined with smaller-than-conventional collection surfaces (10 ft^2/ 1000 cfm) may tend to balance this disadvantage. It is also claimed that the unit can handle face velocities of 2000 to 3000 ft/min, while those of conventional precipitator velocities are on the order of 500 ft/min.

Chemical Additives

Wheelabraton-Frye, in an EPRI funded study to investigate SO_2 removal through the addition of chemical additives such as sodium biocarbonate, has found that some chemical additives apparently are effective in removing fine particulates or agglomerating them so that the collection efficiency of a fabric filter (baghouse) is greatly enhanced. In one study, test results indicated that the concentration at the outlet of the baghouse was decreased from 0.003 grains/acf to 0.0005 grains/acf, apparently due to the addition of sodium bicarbonate.(5-35) The TVA* is also interested in this possible technique. (5-36) Wheelabraton apparently has no external funding for additional research for this technology at present, and TVA's effort will be internally funded.

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* TVA = Tennessee Valley Authority

Comparison of Techniques

In this section the various novel technologies will be compared with respect to efficiency, energy consumption, cost, liquid and solid residuals, and possible applications. In most cases the novel devices are in the laboratory or pilot plant stage and are still undergoing substantial research and development. For this reason, there is not sufficient data available to make meaningful extrapolations to full-scale units for use in industry. Direct comparison is also made difficult by the fact that work by different researchers has been conducted with particles of differing size and chemical composition. Standardized testing would simplify direct comparison, but no standardization exists.

Of particular significance to this study is a project, funded by a group of New England utilities, now underway which will evaluate the applicability of various new control devices to fossil-fuel-fired power plant boilers.(5-37) This study will attempt to provide details on the possibilities of retrofits, actual plant design drawings, logistics, and fuel strategies. The project will include EFBs, filters, wet scrubbers, and ESPs with ionizers.(5-37) This study, as well as additional pilot plant studies of the individual technologies, will provide much of the data which is required for the comparison of novel technologies. Also underway is a study by Ariman, (5-38) funded by DOE and NSF, to survey the emerging technologies for fine particle control. Both of these recently funded studies should be considered in the evaluation of potential fine particulate control technologies for future application.

For purposes of this section the efficiency of a control device is defined to be its fractional collection efficiency for the fine particulate range ($\leq$3 um diamter). Where such data is not available, the efficiency will be stated in the terms used by the researchers for that technology.

Electrified Filter Bed (EFB)

The electrified bed has been applied to low sulfur oil ash collection by Melcher.(5-39) It collects approximately 80-90% of the submicron aerosol during the first 5-6 hours of operation. At the end of a 24-hour continuous operational period, the collection efficiency has dropped to roughly 70-75%. The test aerosol had a gas temperature of 350°F at 100 CFM flow from a by-pass of the main gas flow stream of the M.I.T. Central Utility Plant. The incoming particulate concentration was of the order of 0.01-0.06 grains/scf. The bed material was 0.8 to 2.0 mm size sand grains and 1.0 mm size glass beads.

Melcher (5-40) has also applied the EFB to asphalt fumes from a small-scale prototype asphalt plant and from a bypass at a full-scale plant. In both cases, a baghouse was operated ahead of the EFB to collect the larger particles. At the small-scale facility collection efficiencies ranged from 93-96% for incoming particulate concentrations of 44-167 mg/m^3 for a collection medium of 2.0 mm sand and a gas temperature of up to 500°F. The incoming dust had a mass median diameter (MMD) of 0.3-0.5 um with a geometric standard deviation (o_g) of 2. Pressure drop in the bed was less than 18 cm of H_2O. The tests on the by-pass to the full-scale unit resulted in 99 percent collection efficiency for particulate loadings of 4-41 mg/m^3 at 400 cfm. The aerosol MMD was 0.35, and the o_g was 1.4.

Piispanen, Bradway, and Shortell (5-41) tested an EFB on another asphalt plant and found the collection efficiency to be 98 percent for particles less than 2 um in diameter. Inlet mass loading was 0.3585 gr/scf for the 285-439 acfm flow rate and 140°F stack gas. In this series of tests the collection efficiencies apparently decreased for larger particle sizes, although the reason for this phenomenon was not determined.

Alexander (5-42) found the collection efficiency of an electrified filter bed (non-fluidized) to be 98.7-99.9% for a demonstration at a coal-fired power house. The aerosol was found to be bi-modal with an MMD of 2 um. The stack parameters for this test were: stack flow, 600-1000 acfm; temperature, 275-375°F; mass loading, 0.2-1.0 grams/m^3. The bed material was crushed glass and gravel. During this test it was discovered that the bed was 90% efficient with both the bed and charger inoperative and 94% efficient with only the charger in operation. Melcher (5-43) has also noted this effect, especially for particle sizes of 3 um minimum diameter.

Alexander (5-42) is currently in the early stages of full-scale testing at an asphalt plant emitting 20,000 cfm of stack gas. This full-scale test should provide good data for extrapolation to wide scale-use in industry.

He has also conducted recent power plant pilot tests which apparently confirm that the EFB is capable of 99% efficiency on submicron particles.

Eustis (5-44) at Stanford University is working on an EPRI-sponsored contract which, to date, indicates that the collection efficiency of a laboratory granular bed system can be improved by 20-30% for 0.5 um particles by the application of an electric field. The granular bed system exhibits better than 90% efficiency without the applied field.

The fluidized version of the EFB has a lower pressure drop, but the fixed ("packed") bed exhibits a higher collection efficiency. Both types of units, however, have very high collection efficiencies on a 20,000 cfm unit. Operational costs will be better defined in the near future.

Electrified filter beds, as currently designed by EFB of Woburn, Mass., have an energy usage of approximately 1 h.p. per 1000 cfm, primarily for the fan used to generate the 6 inches of H_2O pressure drop in the bed. A small energy expenditure of approximately 100 watts per 10,000 cfm is required for the corona charging mechanism. (5-45) The current testing on a 20,000 cfm unit will better define operational cost in the near future.

Dietz (5-46) is currently attempting to reduce the energy usage of electrified beds by using image charging of particles instead through use of an applied field.

The present flange-to-flange cost for an electrified filter bed system designed for 20,000 cfm would be approximately $50,000 without installation. Additional cost data will be available during 1979 and 1980 as current full-scale tests are completed.(5-47)

The basic residuals (waste products) from an electrified filter bed system are the bed materials and the collected particulates. The normal residuals would be glass, sand, clay, slate, and the collected ash or other particulates. In the future, if chemically active components are added to the bed media to further enhance collection, as Harvard (5-48) is now doing for moving granular bed filters, the waste handling might be somewhat more complicated than envisioned at present. The current EFB configurations utilize hoppers or similar containers to collect and remove the waste on a periodic basis. The amount of media required would be highly dependent upon the process emissions and the flow. More data should be available as a result of test work in process by Alexander, Dietz, and others.(5-49, 5-50)

Electrified filter beds have been successfully applied to operations emitting oil ash and to emissions from asphalt reprocessing operations and coal-fired boilers on a pilot scale. Full scale tests are now in progress on an asphalt line and additional pilot tests are underway on a power generating boiler.(5-51) The technique would appear to be applicable to emissions from a high temperature operation, such as fluidized bed combustion (5-52), or to the inlet to a gas turbine engine.(5-53) The prime advantages of EFBs in specific applications are that; they have very high collection efficiencies for submicron particles. they do not foul as easily as a fabric filter or an ESP for certain small particle sizes and hydrocarbon emissions, and they do not create the waste disposal problem of a wet collector such as a scrubber. The collected particulates can also occasionally be reused, as evidenced in the asphalt reprocessing application.(5-54) This latter advantage might provide a possible application in the non-ferrous metal industries, such as copper and phosphorous, where recovery could be an economic asset.

Electrostatic Capture in Fiber Beds

Reid and Browne (5-55) determined that an electrostatically augmented filter had a collection efficiency of greater than 90% for 0.6-0.7 um particles of NH_4Cl, Na_2O, and MgO. The particle resistivities were 10^8-10^{12} ohm-cm in the 300 fpm gas flow range. They also found that the efficiency increased linearly with decreasing flow rate (99% for 100 fpm in a concentration of 100 mg/m^3). Pressure drops were small (0.1-1.2 in H_2O).

Lamb (5-56) is currently involved in a combined industry and EPA-sponsored project to develop filtration improvements through the use of electric fields. At this time he believes that the collection efficiency of conventional filters can be increased from 99.5% to 99.9% using electrostatic augmentation. A concomitant reduction in pressure drop across the filter is expected.

Much work is also being conducted in the pilot stage and in full-scale installations with electrostatically augmented baghouses at TVA (5-57), at Carnegie-Mellon (5-58), EPRI (5-59), Research Triangle Institute (5-60), and Notre Dame.(5-61) This work seems to bear out the results mentioned here.

Most of the detailed data on cost and energy usage for electrostatic fiber beds is being developed in connnection with electrostatically augmented baghouses. Most of the "novel" devices are in the research and development stage and energy usage and cost have not been addressed.

The waste products from a particulate filtration process are simply the filter media and the collected particulates. In the work of Reid and Brown at Battelle Northwest, the filter media was polypropylene and teflon. Other possible media would be glass fiber and various cloths.

Aside from applications to baghouse units, which are discussed elsewhere in this report, the electrostatically augmented filter could possibly be applied to any application now using particulate filtration as a control mechanism. The reduced pressure drop that apparently accompanies the use of the applied field should increase the capabilities of filters used in higher flow gas streams.

If future development is consistent with the success of results to-date, electrostatically augmented filters could be applied to such emission sources as the reverberatory furnace in the copper industry.

Agglomeration Technologies

At present the only agglomeration technique which seems practical and economically feasible is the use of acoustics as the agglomerating mechanism. It is difficult to define effectiveness, cost, and energy requirements when discussing sonic agglomerators. At present, the technology is still developing and different researchers have different opinions as to the cost/effectiveness of the devices. Also, since acoustic agglomerators are only dust-conditioning devices, efficiency and overall power requirements will depend on the downstream collector employed.

In the MRI (5-62) study, it was concluded that for agglomeration to be of significant help in the collection of fine particles, the ratio of the final to initial mean particle diameter must be in the range of 5 to 20. The lower end of the range would require the use of a high efficiency system as the collector (i.e., ESP, fabric filter or venturi scrubber) while the upper end would allow the use of a low efficiency system (e.g., cyclones) as the collector. Estimates of the energy consumption of sonic systems using sound levels of 160 db (for reasonable residence times) are in the range of 5 to 20 hp/1000 cfm. To achieve efficiencies which would meet air quality standards, a sonic agglomerator would be most useful when employed with high efficiency devices to improve collection in the fine particle range. Therefore, probable energy requirements in this usage would be on the order of 5 to 10 hp/cfm. For fabric filters and ESPs this represents a fairly high increase over their normal energy consumption rates. Venturi scrubbers typically use 10 to 20 hp/1000 cfm, but since most of the energy goes into removing fine particles acoustic agglomerators might reduce power costs in this area.

Scott (5-63) feels that with the use of a resonant pulse-jet as the sonic generator, efficiencies of acoustic power generation could be increased. Using the progressive saw-tooth waves produced, the need for large agglomeration chambers (along with the associated acoustic frequency, timing and control requirements) would be eliminated. He also feels that acoustic conditioner/wet-scrubber applications hold the most promise. He states that by achieving an increase in mean particle size by a factor of only 3 to 5 in the size range below 0.5 um, acoustic conditioning can be shown to have economic advantages based upon scrubber power savings alone.

Residuals from agglomerator/collector hybrid systems would depend on the collection device employed.

Magnetic Separation

The effectiveness of the HGMS process varies with the operating parameters selected. Experimental results indicate that overall mass efficiencies greater than 99% can be achieved for submicron particle collection. When projected energy requirements are maintained relative to those of conventional devices, collection efficiencies greater than 90% were achieved.

In the study by Gooding, et.al., (5-64) a preliminary economic analysis was made of costs and energy requirements for industrial scale basic oxygen furnace applications. Since information on HGMS auxilary equipment (ducts, dampers, collected dust handling equipment, etc.) and installation costs are not yet established for particulate control applications, the information presented was limited to flange-to-flange device cost and operating power requirements. Also, since HGMS particulate control has been demonstrated only on bench-scale and pilot-scale equipment, the scale up factor is in doubt. The full-scale HGMS estimates were based on modules consisting of commercially available magnets (complete with power supplies and cooling equipment) arranged in a multi-path parallel flow configuration for cyclical operation with an 80% duty cycle and low capital costs, but this application has not yet been demonstrated in gas streams.

All estimates were made assuming that a 99.9% overall mass collection efficiency would be achieved. The flange-to-flange cost estimate for an HGMS system was projected to be \$3.14/cfm (1977 dollars). In terms of power requirements the HGMS process is estimated to use 1.4 hp/1000 cfm. In its present configuration, the unit is designed for completely dry removal of particulates. This would be beneficial if the matter recovered could be used. It also eliminates the need for liquid waste treatment or disposal.

Foam Scrubbing

Small-scale experiments with foam scrubbing techniques seem to indicate that a collection efficiency of 90% is possible for fine particles. Residence times for this efficiency are on the order of 40 to 60 seconds. Calculations show that in order to achieve higher efficiencies (on the order of 99%) residence times of 100 seconds or greater are necessary. Additional developments will be needed to test the performance of the device in industrial applications. The residence times required to achieve collection efficiencies which will meet air quality standards may be impractical.

Based on the experience obtained from operating a foam scrubber on bench and small pilot scales, an economic evaluation of this device was performed.(5-65) The estimated costs vary with bubble residence time and unit design capacity. Operating costs are given for a residence time of 40 seconds. For a 10^5 acfm unit, an operating cost of about $4.5/acfm is projected. The capital cost for the unit is estimated to be on the order of $200,000. Of course, to achieve higher efficiencies much longer residence times would be required, thereby increasing operating and capital costs significantly. Energy consumption of the units has not been addressed specifically. Residuals are in the form of liquid waste and there are no indications of whether or not the treatment of such wastes is included in the operating costs.

Novel Electrostatic Precipitation Devices

There is not much data available on the three precipitation devices discussed earlier. The wet-wall electroinertial unit and the fluid electrode precipitator seem capable of collection efficiencies of greater than 90%. However, these units were designed with the textile industry in mind and were tested on cotton particulates characterized by fairly large mass median diameters. Information on estimated operating and capital costs was not available. However, it was noted that the energy consumption of wet-wall electroinertial units would be approximately 500 watts/1000 cfm.

The trielectrode electrostatic precipitator was designed in order to improve a conventional precipitator's collection of high resistivity dust. Experiments successfully demonstrated this device, showing collection efficiencies typically greater than 95% for high resistivity dust as compared to only 50% for a conventional precipitator. No information for capital costs or energy consumption were given for this device.

Summary of Conclusions

Table 5-1 summarizes the comparison of various technologies. It is apparent that all these technologies show definite promise for fine particulate control, but due to the developmental nature of these techniques it is difficult at present to predict just how wide-spread their future uses could be. In many cases, a combination of conventional and novel techniques should be useful. For example, sonic agglomeration coupled with wet scrubbing could be an extremely efficient and cost effective approach to fine particle control. Also, the use of electrostatically augmented filters, either in a conventional baghouse configuration or in a fiber filter configuration, should be widely applicable to those emissions now controlled by filtration. The electrified filter bed (EFB) has undergone perhaps more commercial type testing than the other advanced systems and shows promise for many applications. The EFB could also allow economical utilization of waste products. Magnetic separation is a highly efficient collection technique for ferromagnetic materials and could also allow recovery of valuable waste products. Foam scrubbing and the novel ESPs studied have not been developed to the point of predicting their wide-spread use; however, the wet wall and fluid electrode precipitators have indicated their usefulness for textile emission control applications.

Of all the devices studied, the EFB is perhaps most ready to be applied on a wide-scale in industry. However, evaluation of each of these advanced systems is recommended for any given emission source for which conventional control techniques are not suitable.

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APPENDIX IVA

Attenuation of Radon Flux and Gamma Exposure Rate from Uranium Mill Tailings

APPENDIX IV-A

Analytical Approach

Radon Flux Attenuation

Background radon flux and gamma radiation data are obtained from measurements taken at the proposed tailings impoundment site prior to construction. The radon flux attenuation by a cover material is typically calculated by use of an analytical model, a number of which have been developed. A model developed at Dames & Moore and applied to a number of tailings piles considers the surface flux (J) released from an infinitely thick slab of tailings covered by two finite slabs which are also radon flux sources. This model can be used to evaluate cover thicknesses when the tailings pile consists of a slimes layer (assumed infinitely thick) covered by a sands layer (finite) or where the cover is composed of layers of different materials (clay cap overburden) (Figure A.1). The model also reduces to a single slab model when only one cover is considered.

Initially the radon fluxes from the various layers are calculated as if they were infinite, using the following equation,

$$J_n = C_v E_n \sqrt{\lambda D_n} = P_n \sqrt{D_n / \lambda} \qquad (1)$$

where:

J_n = surface radon emanation from an infinite slab source (pCi/cm^2-sec)

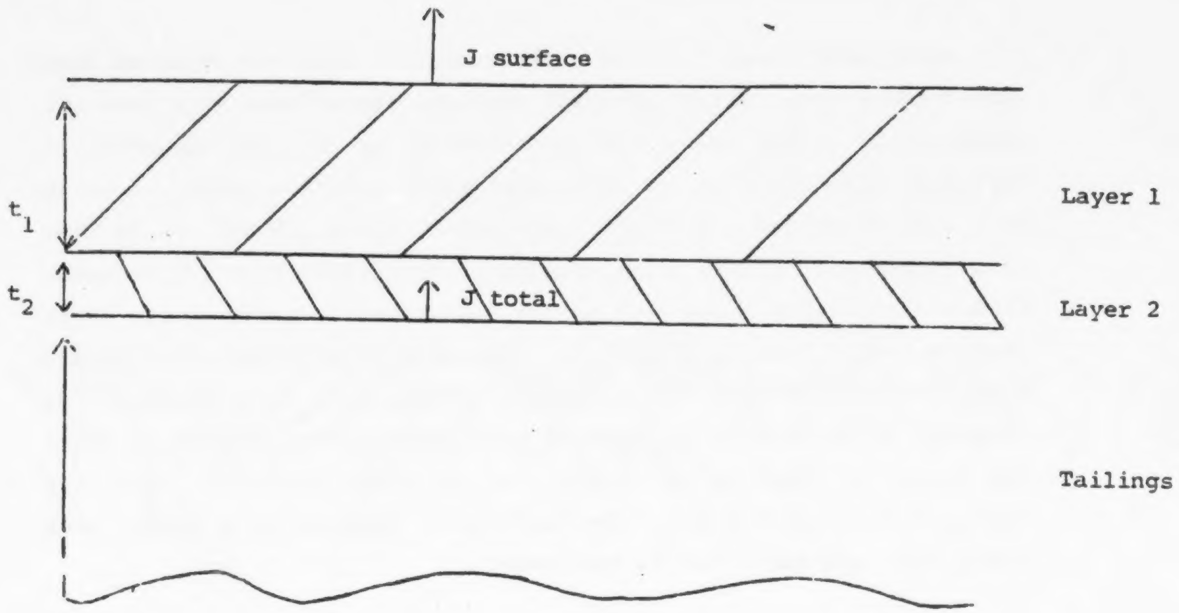
C_v = radium 226 bulk concentration in the slab (pCi/cm^3)

E_n = emanation coefficient for Rn-222

λ = decay constant Rn-222 (sec^{-1})

D_n = effective diffusion coefficient (cm^2/sec)

P_n = radon production rate (pCi/cm^3-sec)


J surface
t_1
Layer 1
t_2
J total
Layer 2
Tailings

CONFIGURATION USED TO MODEL
RADON FLUX ATTENUATION

FIGURE A.1

The second step uses the model to calculate the flux (J) from the surface of the covered tailings. The derivation of the model is shown below. Each layer of material is assumed to contain different quantities of radium (C_v) which generate varying radon contributions to the surface flux (J). Similarly, each material is assumed to have different values for D_n, E_n, and density. Steady state conditions are assumed throughout. The equations for two attenuating cover layers over the tailings layer are;

Layer 1: $$D_1 \frac{\partial C_1}{z^2} - \lambda C_1 + P_1 = 0 \qquad (2a)$$

Layer 2: $$D_2 \frac{\partial C_2}{z^2} - \lambda C_2 + P_2 = 0 \qquad (2b)$$

Tailings: $$D_3 \frac{\partial C_3}{z^2} - \lambda C_3 + P_3 = 0 \qquad (2c)$$

where:

C_1, C_2, C_3 = Radon concentrations in the interstitial spaces of cover layer 1, cover layer 2, and tailings, respectively (pCi/cm^3)

D_1, D_2, D_3 = Effective diffusion coefficients of the three layers (cm^2/sec)

P_1, P_2, P_3 = Radon production rates in the three layers (pCi/cm^3-sec)

λ = Radon-222 decay constant (sec^{-1})

The appropriate boundary conditions are:

$$-D_1 \left.\frac{\partial C_1}{\partial z}\right|_{z = t_1} = -D_2 \left.\frac{\partial C}{\partial z}\right|_{z = t_1} \qquad (3a)$$

$$-D_2 \frac{\partial C_1}{\partial z}\Big|_{z = t_2} = -D_3 \frac{\partial C}{\partial z}\Big|_{z = t_2} \qquad (3b)$$

$$C_1 \ (z=t_1) = C_2 \ (z=t_1) \qquad (3c)$$

$$C_2 \ (z=t_2) = C_3 \ (z=t_2) \qquad (3d)$$

$$C_1 \ (z=0) = 0 \qquad (3e)$$

$$\lim C_3 \ (z) = P_3/ \qquad (3f)$$

$z \dashrightarrow$

where:

t_1 and t_2 are the thicknesses of the cover material.

Using the above, it can be shown that the flux at the surface reduces to:

$$J = \sqrt{D_1 D_2} \ \frac{Bf\ (Ji) + Ag\ (Ji)}{\sqrt{D_2}\ B \sinh(r_1 t_1) + \sqrt{D_1}\ A \sinh(r_1 t_1)} \qquad (4)$$

where:

$$f(Ji) = \frac{J_2}{\sqrt{D_2}} + \frac{J_1}{\sqrt{D_1}}\left(\cosh\ (r_1 t_1) - 1\right) + \frac{J_3 \sqrt{D_2} - J_2 \sqrt{D_3}}{\sqrt{D_2\ D_3}} \ \cosh\ (r_2 t_2) \qquad (5a)$$

$$g(Ji) = \frac{J_1}{\sqrt{D_2}} \sinh\ (r_1 t_1) - \frac{J_3 \sqrt{D_2} - J_2 \sqrt{D_3}}{\sqrt{D_2\ D_3}} \ \sinh\ (r_2 t_2) \qquad (5b)$$

$$A = \sinh\ (r_2 t_2) + \sqrt{D_2/D_3}\ \cosh\ (r_2 t_2) \qquad (5c)$$

$$B = \cosh\ (r_2 t_2) + \sqrt{D_2/D_3}\ \sinh\ (r_2 t_2) \qquad (5d)$$

$$r_1 = \sqrt{\lambda/D_1} \tag{5e}$$

$$r_2 = \sqrt{\lambda/D_2} \tag{5f}$$

and J_1, J_2, J_3 is the flux from each material if it were infinite in extent.

A computer program was developed to solve the right hand side of equation 4 and to allow ease in varying the parameters of the model.

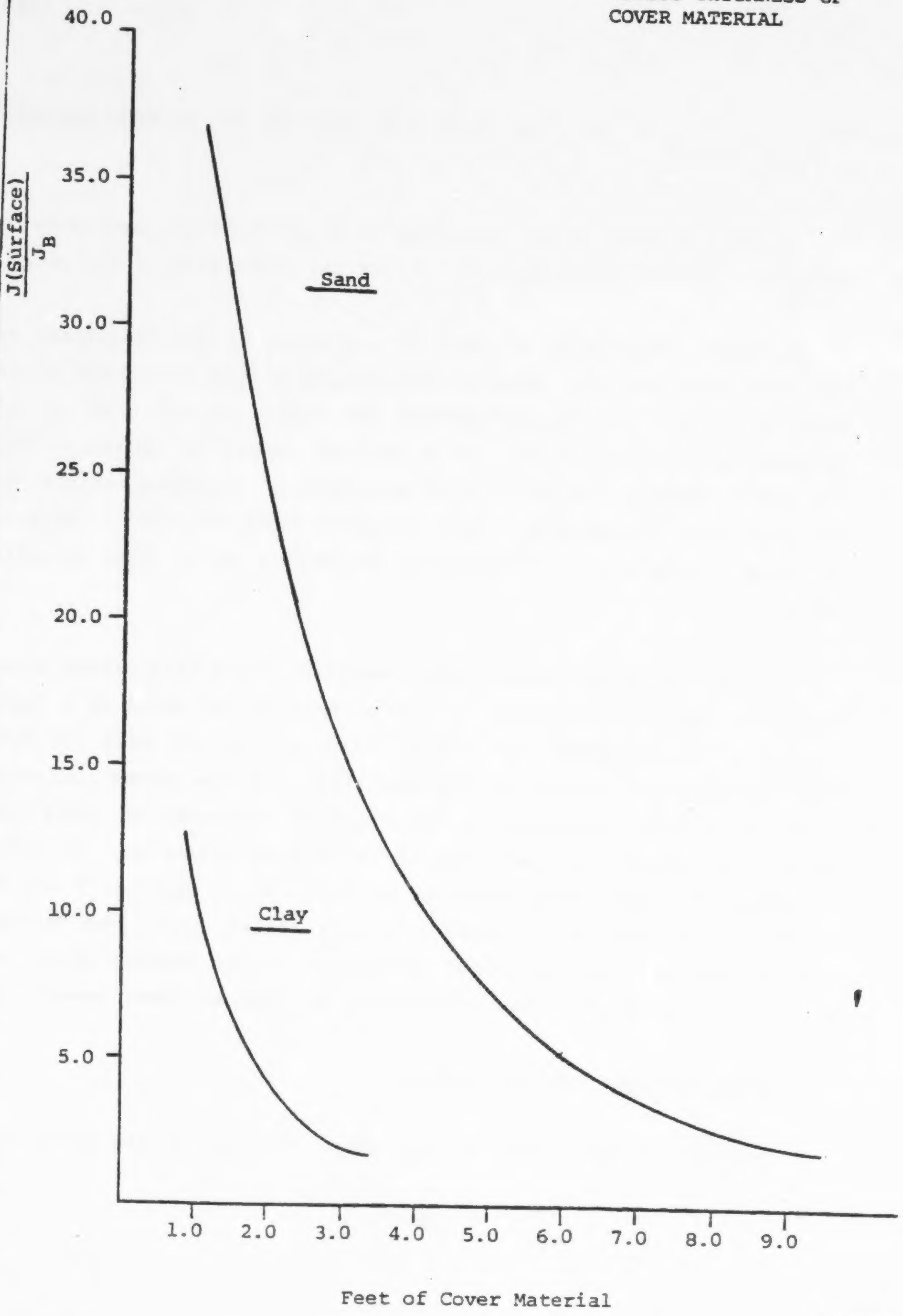
A major shortcoming of this or any model is the meagerness of the data base for the various parameters of the available cover materials. Most of the parameters are based on old (>10 years) experimental work performed on a limited number of materials and moisture contents. A high level of uncertainty, therefore, exists for the calculated thicknesses. This situation could be greatly improved by using parameters experimentally determined on a site specific basis.

Figure A.2 shows typical radon emanation rates (calculated using the above described approach) at the surface of the cover as a function of cover thickness for typical clay and typical sand (in this case the model was reduced to a single slab). As the curves indicate, there is a wide variation in the required thickness of cover materials to achieve the same reduction in surface emanation, the twice background standard being achieved by 3 1/2 ft of clay, or 9 1/2 ft of sand. In addition to these materials shales, silt, and various combinations of these materials indigenous to the regions where the mills are located are often considered for use as cover materials.

Gamma Exposure Rate Attenuation

Inasmuch as each foot of any cover will reduce the gamma ex-

RATIO OF SURFACE FLUX
TO BACKGROUND FLUX
VERSUS THICKNESS OF
COVER MATERIAL



DAMES & MOORE

FIGURE A.2

posure by approximately one order of magnitude, the thickness required to achieve the necessary reduction in radon flux will usually be more than sufficient to reduce gamma radiation to background levels.

APPENDIX IVB

Catalogue of Investigated Research on Advanced Control Technologies for Radionuclide Emissions

CONTROL TECHNOLOGY RESEARCH SURVEY

Principal Investigators: Maeck, W.J.; Pence, D.T.

Location: Idano Nuclear Corp., Idaho Falls, Idaho

Title of Research: Application of Metal Zeolites to Radioiodine Air Cleaning Problems

Sponsoring Agency or Source of Funding:

Cumulative Funding:
Start Date:
Projected Funding:
Completion Date:

Publications: 11th AEC Nuclear Air Cleaning Conference, pp. 607-620, 1970.

Control Technology/Process: Iodine sorption on metal impregnated zeolites.

Description of Research:

This paper briefly reviews existing iodine species adsorption, applications, and economics data for metal zeolites.

Laboratory studies have shown that silver zeolite is a highly efficient adsorbent for airborne methyl iodide and elemental iodine. The potential use of metal zeolites, other than silver, for the adsorption of elemental iodine is most encouraging and suggests the use of mixed beds for maximum material utilization.

- i.e., the use of two or more beds

The first bed conceivably composed of lead zeolite would function primarily as an elemental iodine adsorbent and the final bed composed of silver zeolite would serve as an adsorbent for organic iodides and for traces of elemental iodine passing the first bed.

The use of heated beds increases tne operational flexibility of metal loaded zeolites, and the use of mixed beds shows promise for better utilization of the bed material.

Based on a review of the economics of silver zeolite, it appears that the use of this material in air cleaning systems is practical. One intangible item of comparisons not considered is safety.

CONTROL TECHNOLOGY RESEARCH SURVEY

Principal Investigators: Holladay, D.W. and Haag, G.L.

Location: Oak Ridge National Lab

Title of Research: Removal of C-14 Contaminated CO_2 From Simulated LWR Fuel Reprocessing Off-Gas By Utilizing the Reaction Between CO_2 and Alkaline Hydroxide in Either Slurry or Solid Form

Sponsoring Agency or Source of Funding:

Cumulative Funding:
Start Date:

Projected Funding:
Completion Date:

Publications: 15th DOE Nuclear Air Cleaning Conf., pp. 547-567, 1979

Control Technology/Process: Reaction of CO_2 with alkaline slurries in agitated tank type contactors

Description of Research:

The research considered C-14 removal from LWR fuel reprocessing off-gas. The removal of C-14 contaminated CO_2 from simulated LWR off-gases was studied as a function of operating conditions, etc.

The removal of CO_2 from simulated LWR fuel reprocessing off-gases containing 0.033% CO_2 air and 1-5% CO_2 air has been shown to be feasible for gas processing with both alkaline slurries in agitated contactors and hydrated barium hydroxide in packed beds. It appears feasible to obtain CO_2 decontamination factors (DF_s) of 10^2 to 10^3 for tractable sizes of equipment and operating conditions.

The use of solid $Ba(OH)_2$ offered possibilities of an operationally simpler and less expensive process than the $Ca(OH)_2$ slurry contactor with its ancillary $CaCO_3$ recovery equipment. A disadvantage, however, of $Ba(OH)_2$ was the expense relative to $Ca(OH)_2$.

The gas feeds that have been studied are those which simulate the composition of LWR fuel reprocessing off-gases as they would occur at the end of the off-gas processing train where I_2, NO_x and Kr would already have been removed. Further experiments will be conducted to determine the effect of placing the CO_2 removal processes at optional sites in the off-gas processing train where such contaminants as I_2 and NO_x could compicate the operation. Additional experiments are needed for optimization of operating parameters and scaleup.

CONTROL TECHNOLOGY RESEARCH SURVEY

Principal Investigators: Laser, M; Barnert-Wiemer, H.; Beaujean, H.; Merz, E.; Vygen, H.

Location: Institute for Chemical Tech-Kernforschungsanlage Julich GmbH, Federal Republic of Germany

Title of Research: AKUT - A Process for the Separation of Aerosols, Kr, and H-3 from Burning Off-Gas in HTR-Fuel Reprocessing

Sponsoring Agency or Source of Funding:

Cumulative Funding:
Start Date:

Projected Funding:
Completion Date:

Publications: 13th AEC Air Cleaning Conf., pp. 246-262, 1975.

Control Technology/Process: Cs, I - ESP
Kr - cryogenic distill
H-3, I - adsorption or chemical reaction

Description of Research:

The AKUT process for burner off-gas in HTR fuel reprocessing consists of:

"- aerosol retention by an electrostatic separator followed by HEPA filters;
- oxidation of CO with O_2 or reaction of excess O_2 with CO, respectively;
- compression;
- scrubbing and/or liquefaction;
- separation of krypton by distillation;
- separation of tritiated water and iodine by adsorption or chemical reaction."

CONTROL TECHNOLOGY RESEARCH SURVEY

Principal Investigators: Yarbro, O.O.; Mailen, J.C.;
W.S. Groenier

Location: Oak Ridge National Laboratory, Oak Ridge, Tenn.

Title of Research: Iodine Scrubbing From Off-Gas With Concentrated Nitric Acid

Sponsoring Agency or Source of Funding:

Cumulative Funding:

Start Date:

Projected Funding:

Completion Date:

Publications: 13th AEC Air Cleaning Conf., pp. 832-844, 1973.

Control Technology/Process: Wet scrubbing removal of iodine via concentrated nitric acid (Iodex process).

Description of Research:

"A new process, named Iodox, for effectively scrubbing all iodine forms from off-gas streams with concentrated (20 M) nitric acid has been developed. This process removes all significant iodine species, both elemental and organic, from a gas stream by oxidizing them to the non-volatile iodate form.

Advantages of the Iodex system for removing iodine from nuclear fuel reprocessing plant off-gas include:

1. It is capable of removing kilogram quantities of iodine while delivering a concentrated iodine waste stream for permanent disposal.

2. It is relatively insensitive to the contaminants normally found in a reprocessing plant off-gas stream and effectively removes all significant iodine forms.

3. Nitric acid is used in the process; thus no significant chemicals are introduced to the plant process or waste handling systems.

Laboratory-scale studies indicate that iodine retention factors in excess of 10^4 for methyl-iodide can be obtained in a multi-staged bubble-cap column. A small engineering-scale demonstration of the complete process, including the iodine scrubbing column, iodine waste concentration and solid I_2O_5 handling, and acid reconstitution and recycle, is in progress. The flowsheet being used for the engineering-scale system demonstration in typical of an application of the Iodox process to a fuel reprocessing plant.

CONTROL TECHNOLOGY RESEARCH SURVEY

Principal Investigators: Copper, M.H.; Simmons, C.R.; Taylor, G.R.

Location: Advanced Reactors Division, Westinghouse Electric Corp., Madison, Pennsylvania

Title of Research: Adsorption of Kr from He by Low Temperature Charcoal

Sponsoring Agency or Source of Funding:

Cumulative Funding: Projected Funding:
Start Date: Completion Date:

Publications: 13th AEC Air Cleaning Conf., pp. 151-176.

Control Technology/Process: Krypton adsorption onto charcoal

Description of Research:

Adsorption of Kr from He by charcoal at - 100°C - 140°C was experimentally investigated to verify adsorption system design methods and to determine effects of regeneration for the Gas Purification System of the Liquid Metal Last Breeder Reactor.

CONTROL TECHNOLOGY RESEARCH SURVEY

Principal Investigators: Ford, Bacon & Davis

Location/Phone Number: (801) 583-3773

Title of Research: The Evaluation of Alternatives for the Ultimate Disposal of Kr-85

Sponsoring Agency or Source of Funding: U.S. Environmental Protection Agency

Cumulative Funding: Projected Funding:

Start Date: Completion Date:

Publications: Report dated February, 1979

Control Technology/Process:

Description of Research:

"A survey of the literature is presented on the possible means of immobilizing krypton-85, an inert fission product gas that poses a radiological hazard if released to the atmosphere. The literature on disposal and storage of krypton has been reviewed and summarized in Chapter 2. The alternative methods are categorized into the following principal techniques: (1) 500 or 2000 psi gas, (2) zeolites, (3) loaded solid set in a matrix, (4) ion implantation/sputtering, (5) metal vapor deposition, (6) clathrates, (7) porous underground media, (8) hydrofracture, (9) extraterrestrial disposal, (10) disposal in the ocean, (11) adsorbents, (12) transmutation, (13) cryogenics, (14) low-pressure storage in caverns, (15) low-pressure storage in tanks, (16) solutions, and (17) combinations of the foregoing. A bibliography is given for each technique. Chapter 3 contains a summary of the available body of knowledge on each technique. The techniques are to be evaluated in more detail in subsequent tasks of this project."

CONTROL TECHNOLOGY RESEARCH SURVEY

Principal Investigators: Wilhelm, J.G.; Schuettelkopf, H.

Location: Radiation Protection and Safety Department,
Karlsruhe - Nuclear Research Center,
Federal Republic of Germany

Title of Research: Inorganic Adsorbic Materials for Trapping of Fission Product Iodine

Sponsoring Agency or Source of Funding:

Cumulative Funding:

Start Date:

Projected Funding:

Completion Date:

Publications: 11th AEC Nuclear Air Cleaning Conf., pp. 640-651

Control Technology/Process: Inorganic adsorption of iodine

Description of Research:

Application of research: Off-gas cleaning for fuel reprocessing plants and gas cleaning inside the reactor containment under MCA conditions. Experimental work is performed to evaluate the usefulness of different experimental Bayer catalytic carriers (KTB, KTC, KTD), and zeolites impregnated with $AgNO_3$. Impregnation with KI was also tested.

The results are presented in Tables II, III, IV, V, and VI of the above reference. $AgNO_3$ - impregnated KT material could be a useful adsorber material for fission product iodine with special suitability for off-gas cleaning in reprocessing plants. Due to the small amount of silver needed for the impregnation of the KT material, the price will be relatively low.

CONTROL TECHNOLOGY RESEARCH SURVEY

Principal Investigators: Ammon, R.V.; Burkhardt, H.G.; Hulter, E.; Neffe, G.

Location: Kernforschungszentrum Karsruhe GmbH, Federal Republic of Germany

Title of Research: Development of a Cryogenic Krypton-Separation System for the Offgas of Reprocessing Plants

Sponsoring Agency or Source of Funding:

Cumulative Funding:
Start Date:

Projected Funding:
Completion Date:

Publications: 15th DOE Nuclear Air Cleaning Conf., pp. 640-651

Control Technology/Process: Cryogenic distillation of first N_2-Kr-Xe, then Kr-Xe mixtures

Description of Research:

Acryogenic separation of rare gases from reprocessing offgas scheme is discussed and compared with other offgas purification flowsheets. Some features pertinent to the cryogenic separation scheme were studies experimentally.

The Kernforschungszentrum Karlsruhe scheme for reprocessing offgas includes:

Separation of O_2 and residual NO_x by catalytic reduction with He.

Adsorptive retentin of H_2O, CO_2, NH_3 etc.

Cryogenic distillation of first N_2-Kr-Xe, then Kr-Xe mixtures.

CONTROL TECHNOLOGY RESEARCH SURVEY

Principal Investigators: Whatley, M.E.; Glass, R.W.;
Haas, P.A.; Meservey, A.B.;
Notz, K.J.

Location: ORNL, Oak Ridge, Tenn.

Title of Research: Decontamination of HTGR Reprocessing Off-Gases

Sponsoring Agency
or
Source of Funding

Cumulative Funding:
Start Date:

Projected Funding:
Completion Date:

Publications: 12th AEC Air Cleaning Conference
pp. 86-101, 1973

Control Technology/Process: Kr absorption in liquid CO_2 (KALC process)

Description of Research:

The off-gas from the reprocessing of HTGR fuel is unique among nuclear fuel reprocessing off-gases because of the large amount of CO_2 produced by the burning of the fuel element.

An HTGR fuel element contains approximately ten times as much graphite as heavy metals. The KALC process exploits the fact that Kr is more soluble in liquid CO_2 than O_2, N_2, or CO. The rare gas removal pilot plant at the ORGDP was used to explore the feasibility of operating a KALC system. In addition to demonstrating feasibility, the initial pilot campaign provided encouragement that the KALC process is a good way to decontaminate the HTGR reprocessing off-gases. Development of the KALC process requires:

Obtaining the necessary equilibrium and thermodynamic data for describing the system; selecting, characterizing, and in some cases, developing components required for a radiochemical application of the process; selecting an effective operating mode with its associated control system; demonstrating the performance of an integration system, items two and three have received only sufficient attention to assure that appropriate solutions will be forthcoming. Work on the first and last have already yielded significant results.

CONTROL TECHNOLOGY RESEARCH SURVEY

Principal Investigators: Stein, Lawrence

Location: Argonne National Lab, Argonne, Illinois

Title of Research: Noble Gas Compounds: New Methods for Collecting Radon and Xenon

Sponsoring Agency or Source of Funding:

Cumulative Funding:

Start Date:

Projected Funding:

Completion Date:

Publications: Chemistry, V. 47, pp. 15-20; October, 1974.

Control Technology/Process: Oxidation of Xe-Kr to form a salt.

Description of Research:

Possible oxidants for Xe collection include O_2SbF_6 which has been shown in laboratory tests to remove Xe-133 from air effectively and also separates Kr from Xe; $N_2F^+SbF_6$ and $BrF_6^+AsF_6$ both react with Rn and Xe at 25°C to 100°C.

The advantage is the substitution of a small bed for a larger bed of charocal in a reactor system. Thus the cost of the heavy steel containment vessel is reduced while more importantly stable Xe isotopes would be recovered and used for industrial purposes.

It should be noted that no solid or liquid reagent with sufficient oxidizing power to capture Kr has thus far been found.

CONTROL TECHNOLOGY RESEARCH SURVEY

Principal Investigators: Mahn, A. J.; Pery, C.A.

Location: General Atomic Co.

Title of Research: General Atomic's Radioactive Gas Recovery System

Sponsoring Agency
or :
Source of Funding

Cumulative Funding: Projected Funding:
Start Date: Completion Date:

Publications: 13th Air Cleaning Conf., pp.228-231, 1975.

Control Technology/Process:

Description of Research:

A radioactive gas recovery system has been developed for the HTGR which separates, for the purpose of retention, the radioactive components from the non-radioactive reactor plant waste gases. The system utilizes a chromatographic adsorption process via activated charcoal adsorber columns which provides a mechanism for separating a gas mixture into its constituents.

CONTROL TECHNOLOGY RESEARCH SURVEY

Principal Investigators: Hill, F.B.; Wong, Y.W.; Chan, Y.N.

Location: Dept. of Energy & Environment
Brookhaven National Laboratory

Title of Research: Tritium Removal Using Vanadium Hydride

Sponsoring Agency or Source of Funding: U.S. DOE

Cumulative Funding:
Start Date:

Projected Funding:
Completion Date:

Publications: 15th DOE Nuclear Air Cleaning Conf., pp. 167-174, 1979.

Control Technology/Process: Tritium adsorption onto vanadium hydride

Description of Research:

An experimental study of the equilibrium and kinetic properties of hydrogen isotope exchange on vanadium hydride has been conducted. Tritium is more stably absorbed on vanadium than the lighter isotopes of hydrogen (inverse isotope effect).

Future experimental and theoretical efforts will be required for a conclusive assessment of the usefulness of hydrogen isotope separation via cyclic processes based on the use of vanadium hydride.

CONTROL TECHNOLOGY RESEARCH SURVEY

Principal Investigators: Pence, D. T.; Duce, F. A.; Maeck, W. J.

Location: Idaho Chemical Programs-Operations Office National Reactor Testing Station, Idaho Falls, Idaho

Title of Research: Developments in the Removal of Airborne Iodine Species with Metal Substituted Zeolites

Sponsoring Agency or Source of Funding: USAEC

Cumulative Funding:
Start Date:

Projected Funding:
Completion Date:

Publications: 12th SEC Air Cleaning Conf., pp. 417-433

Control Technology/Process: Iodine sorption on metal substituted zeolites

Description of Research:

Radioiodine adsorption efficiencies and structural properties were examined under adverse environmental conditions such as high temperature and steam atmospheres, high radiation fields, and high levels of various contaminant gases.

Non-silver, metal substituted zeolites show promise in dry atmospheres or heated adsorption bed applications. None compare with silver zeolite for overall adsorption bed efficiency for radioiodine. A review of tests are described in which adsorption efficiencies of several adsorbent materials were examined as a (airborne methyl iodine concentration).

Not enough is known about the adsorption performance of the commonly used radioiodine adsorbents to assure that the required DFs can be obtained to meet the specified radioiodine concentration levels with the present adsorbent systems.

CONTROL TECHNOLOGY RESEARCH SURVEY

Principal Investigators: Pence, D. T.; Duce F. A.; and Maeck, W. J.

Location: Idaho Nuclear Corp., Idaho Falls, Idaho

Title of Research: A Study of the Adsorption Properties of Metal Zeolites for Airborne Iodine Species

Sponsoring Agency or Source of Funding:

Cumulative Funding:
Start Date:

Projected Funding:
Completion Date:

Publications: 11th AEC Nuclear Air Cleaning Conf., pp. 581-599, 1970.

Control Technology/Process: Adsorption of iodine on metal zeolites

Description of Research:

The above reference is a progress report on the research. The major conclusions were:

Methyl iodine adsorption studies on silver zeolite show that, like impregnated charcoal, its adsorption charactivities are adversely affected by high humidity atmospheres, but to a lesser extent; methyl adsorption properties of silver zeolite at high relative humidities appear to be very sensitive to the extent of silver Na exchange.

CONTROL TECHNOLOGY RESEARCH SURVEY

Principal Investigators: Wilhelm, J. G. and Schuttelkopf, H.

Location: Radiation Protection and Safety Dept./Chemistry,
Karlsruhe Nuclear Research Center, Karlsruhe,
Federal Republic of Germany

Title of Research:

Sponsoring Agency
or :
Source of Funding

Cumulative Funding: Projected Funding:
Start Date: Completion Date:

Publications: 12th AEC Air Cleaning Conf., pp. 540-550, 1973.

Control Technology/Process: Adsorption of iodine by $AgNO_3$ impregnated, amorphous silicic acid

Description of Research:

"An inorganic iodine adsorber material on the basis of $AgNO_3$-impregnated, amorphous silicic acid was developed for use in off-gas cleaning systems of fuel reprocessing plants.

Extensive experimental work was performed to evaluate the removal efficiency of this material from off-gas containing NO_2 for elemental iodine and methyl iodine. Experimental data are given on the influence exerted by relative humidity, temperature, amount of NO_2 in the off-gas, granule size of the adsorber material, and iodine loading, on the performance of the inorganic iodine adsorber material. Also some data will be given on this material concerning the iodine loading capacity and desorption behavior of isotopic exchange between iodine in the form of AgI on the surface of the inorganic adsobrer material and iodine in the gas phase will be briefly discussed wth respect to the performance time of the adsorber material; also the effects of radiation exposure are indicated.

Moreover, data will be furnished on the removal efficiency of the inorganic adsorber material in the real off-gas of a fuel reprocessing plant; the operating conditions of full-sized iodine filters for fuel reprocessing plants and the price for off-gas cleaning with the inorganic adsorber material will be discussed."

CONTROL TECHNOLOGY RESEARCH SURVEY

Principal Investigators: Pence, D. T.; and Staples, B. A.

Location: Allied Chemical Corp., Idaho Chemical Programs-Operations Office, National Reactor Testing Station, Idaho

Title of Research: Solid Adsorbents for Collection and Storage of I-129 from Reprocessing Plants

Sponsoring Agency or Source of Funding: USAEC

Cumulative Funding:
Start Date:

Projected Funding:
Completion Date:

Publications: 13th AEC Air Cleaning Conf., pp. 758-764, 1974.

Control Technology/Process: Solid adsorption of iodine

Description of Research:

1) The paper is a literature search and briefly compares proposed methods for collection and containment of I-129 and describes a funded program by the U.S. AEC for Allied Chemical Corp. to evaluate solid adsorbents for the collection and long term storage of I-129.

2) Introduction:

   A) DFs of 10^8-10^{10} will be required for anticipated processing of 30 day valid LMFBR fuel.

   B) DFs of 10^3-10^4 for contemporary fuels will probably be sufficient to reduce airborne levels of iodine low enough to attain the design objectives for I-131 exposure for 150 day and longer cooled fuels.

   C) Iodine removal requirements from reprocessing plant effluents:

      1) Primary iodine removal systems. designed to remove the iodine from the dissolver off-gases.

      2) Secondary removal systems-generally designed to provide additional iodine removal from the dissolver off-gas and iodine removal from the vessel off-gas and other equipment vents.

Description of Research (cont'd):

   3) Final cleanup system provides additional removal after the primary and secondary systems.

3) Several wet scrubbing processes have been proposed for the primary removal system in which the major portion of the 300g ton of spent fuel, 20% of which is stable iodine, will be removed.

   A) Mercuric nitrate-nitric acid method

      1) Elemental and alkyl iodides are readily complexed by the Hg, but the aromatic iodides are more elusive.

      2) The scrubbing solution is periodically taken to a concentrator-evaporator where the iodine is precipitated as $Hg(IO_3)_2$. The supernatant liquid is removed prior to permanent storage of the $Hg(IO_3)_2$.

      3) Capable of DFs of $\approx 10^4$ based upon laboratory tests.

   B) Concentrated nitric acid technique (IODOX process)

      1) Receiving considerable development effort at ORNL in connection with the LMFBR fuel reprocessing development program.

      2) Packed for bubble-cap columns with a counter-current flow of 18-20M nitric and are used.

      3) The process appears to be satisfactory for the removal of all organic iodines, as well as elemental iodine.

      4) Present design calls for the removal of iodine from the nitric acid as HIO_3 which can be converted further to a more anhydrous form for long term storage.

      5) Capable of DFs of 10^4 based upon laboratory tests.

4) Both wet scrubbing techniques and solid adsorbents have been proposed for secondary iodine removal systems.

   A) Alkaline solutions have been shown to contain some of the iodine but tend to promote the formation of species of iodine that are more difficult to remove.

   B) The mercuric nitate-nitric acid wet scrubbing method has also been proposed for secondary iodine removal systems.

5) A number of inorganic adsorbents have been proposed for use in radioiodine removal systems for the primary and secondary removal of iodine from nuclear fuel reprocessing plants.

Description of Research (cont'd):

A) Materials proposed

1) Silver impregnated, amorphous silicic acid.

2) Silver and other metal cation impregnated alumina, and oxides of aluminum and silicon.

B) Impregnated carbons are not considered for treatment of reprocessing plant effluents because of the possible violent reaction of the activated carbon with NO_2 present in the off-gas.

C) Solid, inorganic adsorbents offer several major advantages compared with proposed wet scrubbing methods:

1) Allow a simpler design

2) Comparatively noncorrosive

3) Are in a form that does not require further treatment prior to long-term storage.

4) Readily adapatable to remote operation

5) Long, reliable, maintenance-free operation expected because there are only a few moving parts.

6) Estimated characteristics for solid iodine removal systems:

	Primary	Secondary
Flow Rate - acmm (acfm)	18.4 (650)	142 (5,000)
Surface Area of Bed - m^2(ft^2)	1.2 (13)	9.3 (100)
Bed Depth - cm(in.)	10 (4)	5 (2)
DF	10^3	10^3
Estimated Lifetime Before Changeout (d)	6.5	300 - 600
Estimated Efficiency for Adsorbent Utilization Before Breakthrough (%)	15	10
Cost per day for Adsorbent ($)	300	36
Annual Adsorbent Cost ($)	90,000	10,800

[a] Costs are based on 300-d changeout.

Description of Research (cont'd):

7) Conclusions

A) Primary iodine removal

1) The cost of chemicals to remove iodine in a primary iodine removal system in a nuclear fuel reprocessing plant off-gas stream appears to be 3-5 times less for the mercuric nitrate-nitric acid method than for solid adsorbents.

CONTROL TECHNOLOGY RESEARCH SURVEY

Principal Investigators: Merriman, J.R.; Stephenson, M.J.; Pashley, J.H.; Dunthorn, D.I.

Location: Oak Ridge Gaseous Diffusion Plant ORNL

Title of Research: Removal of Radioactive Kr-Xe From Contaminated Off-Gas Streams

Sponsoring Agency or Source of Funding:

Cumulative Funding:
Start Date:

Projected Funding:
Completion Date:

Publications: 11th Air Cleaning Conf., pp. 175-206, 1970.

Control Technology/Process: Selective dissolution of Kr-Xe in a flourocarbon solvent.

Description of Research:

Two sets of pilot plant experiments were conducted using two flourocarbon solvents over wide ranges of operating conditions. The pilot plant processing capacity has 20 scfm of gas. In the first phase of experiments 34 pilot plant tests were made utilizing refrigerant-12 as the process solvent. In the second phase of experiments, 40 pilot plant tests were made with refrigerant-11.

The pilot plant consisted of 3 functional sections:

Absorber gas contact with solvent; a fractionator, to enrich the gas dissolved in the liquid solvent by removing most of the O_2, N_2, and Ar; a stripper to generate the gas product, highly constructed Kr-Xe and to provide a pure solvent stream for recycle back to the adsorber.

Possible applications of flourcarbon adsorbers include:

BWR Systems, PWR Systems, Fuel Reprocessing Plant, Vented Fuel LMFBR, LWR Accident Case

CONTROL TECHNOLOGY RESEARCH SURVEY

Principal Investigators: Kabat, M.J.

Location: Ontario Hydro, Health Physics Department,
Toronto, Ontario

Title of Research: Monitoring and Removal of Gaseous C-14 Species

Sponsoring Agency or Source of Funding:

Cumulative Funding:

Start Date:

Projected Funding:

Completion Date:

Publications: 15th DOE Nuclear Air Cleaning Conf., pp. 208-230, 1979.

Control Technology/Process: Gaseous carbon compounds are catalytically oxidized for CO_2 adsorbed on solid $Ca(OH)_2$ at elevated T and held in the form of $CaCO_3$. $CaCO_3$ can be immobilized in concrete.

Description of Research:

Possible advantages for LWR reactor gaseous effluent include:

- Large volume reduction factor for CO_2.
- Operationally simple collection process.
- Minimal possibility of radioactive contamination arising.
- Minimal reduction field at the disposal containers surface.
- Negligible release of radionuclides from the container during long term storage.

A theoretical evaluation of the optimum conditions for CO_2 adsorption and liberation is discussed and experimental investigations are described.

CONTROL TECHNOLOGY RESEARCH SURVEY

Principal Investigators: Foster, B.A.; Pence, D.T.;
Staples, B.A.

Location: Allied Chemical Corporation
Idaho Chemical Programs - Operations Office
National Reactor Testing Station
Idaho Falls, Idano 83401

Title of Research: Long Term Storage Techniques for Kr-85

Sponsoring Agency or Source of Funding:

Cumulative Funding:

Start Date:

Projected Funding:

Completion Date:

Publications: 13th AEC Air Cleaning Conf., pp. 293-301

Control Technology/Process:

Description of Research: Literature Base Study - No experimental or pilot plant work

Criteria utilized for evaluating the potential Kr-85 storage methods include:

- Storage capacity
- Thermal and radiation resistance
- Installation and operating cost
- Safety
- Ease of recovery

Potential methods for storage of Kr-85 include:

- High pressure steel cylinders
- Glass plastic or metal capsules
- Injection into soil or underground fans
- Dispersions in glass, metal or plastic
- Absorption or adsorption
- Zeolitic encapsulation
- Clathrate inclusion
- Ionic bombardment
- Sputtering
- Chemical compounds

Description of Research (cont'd):

Three promising methods

High Pressure Steel Cylinders

Advantages

- o Well-established history of development and use in industry
- o Long life with good thermal and radiation resistance
- o High capacity
- o Low cost
- o Ease of future recovery

Disadvantages

- o Possibility of a sudden Kr-85 release
- o The use of cylinders place certain restrictions on the purity of the gas stored.
- o There may be problems associated with the accumulation of the decay product Rb and external erosion.

Zeolite encapsulation

Advantages

- o Definite safety advantage over high P steel cylinders

Disadvantages

- o The storage capacity is expected to not be large due to radiation damage.

Clathrate trapping

- o Appears to be unacceptable for Kr-85 storage. The poor thermal stability limits capacity to such an extent as to make clatharates economically unattractive.

High pressure steel cylinders and zeolitic encapsulation appear very promising.

CONTROL TECHNOLOGY RESEARCH SURVEY

Principal Investigators: Pence, D.T; Chou, C.C.
Christian, J.D.; Paplawsky, W.J.

Location: Science Applications, Inc.
San Diego, California

Title of Research: Noble Gas Separation with the use of Inorganic Adsorbents

Sponsoring Agency or Source of Funding: U.S. DOE, Contract EY-77-C-09-0979

Cumulative Funding:
Start Date:
Projected Funding:
Completion Date:

Publications: 15th DOE Nuclear Air Cleaning Conf.
pp. 519, 522, 1979.

Control Technology/Process: Kr-adsorption decay bed
Xe-adsorption decay bed
not specifically described in paper due to pending patent.

Description of Research:

The purpose of the DOE supported program is the development of an integrated off-gas treatment process for nuclear fuel reprocessing facilities. No vital plant improvements run, only initial column improvements on individual system components.

APPENDIX IVC

Catalogue of Investigated Research on Advanced Control Technologies for Particulate Emissions

CONTROL TECHNOLOGY RESEARCH SURVEY

Principal Investigators: Joseph D. McCain

Location: Southern Research Institute
2000 9th Avenue, South
Birmingham, Alabama 35205

Sponsoring Agency
or : EPA
Source of Funding Dale Harmon

Cumulative Funding:
Start Date: Sept. 1974

Projected Funding:
Completion Date: Jan. 1978

Publications: EPA-600/7-78-093

Control Technology/Process: Wet Scrubber
Entoleter Centrified Scrubber

Description of Research:

Basic wet scrubberwith centripetal vortex contactor which creates average drop size that is smaller than that created by conventional spray contactor at the same energy level. Tests were conducted on emissions from an asphalt plant.

EFFLUENT RELEASE DATA/COMMENT

"The collection efficiency of the Entoleter Inc., Centrifield Scrubber determined by conventional total particulate techniques on a source producing particulate having a mass mean diameter of about 100 um was 99.50 and 99.73 for two days of testing. Measured fractional efficiencies were about 90% at 0.03 um, about 50% at 0.05 um, 20% at 0.1 um, 50% at 0.5 um, 90% at 1 um, and 99.7% at 5 um. The scrubber energy usage during the tests was approximately 2980 JOULES/SCM, (80 BTU/ 1000 SCF) at a pressure drop of 17 cm (6.7 inches) w.c. The Centrified Scrubber was not found to be substantially different in efficiency from the class of scrubbers known as conventional scrubbers." .....the power consumption for the Centrified was somewhat lower but not substantially different from that for a well-designed venturi scrubber giving the same particulate collection efficiency.

Assessment Parameters:

Effectiveness:

Cost:

Air Liquid Solid Residuals:

Energy Consumption:

Comments by PI:

CONTROL TECHNOLOGY RESEARCH SURVEY

Principal Investigators: 1) G. W. Penney, 2) P.C. Gelfand

Location: 1) Elect. Engr. Dept., Carnegie-Mellon Univ.
Pittsburgh
2) Research & Dev. Div., Buell Div. of Envirotech,
200 N. 7th St., Lebanon, PA.

Title of Research: Trielectrode Electrostatic Precipitator for Collecting High Resistivity Dust

Sponsoring Agency or Source of Funding: Unknown

Cumulative Funding:
Start Date:

Projected Funding:
Completion Date:

Publications: JAPCA Vol 28, No. 1, Jan. 1978

Control Technology/Process:

The voltage across the collected dust layer is maintained at a nearly constant potential by the application of short corona pulses at a frequency of about 1/2 the RC time constant. A third electrode is used to provide a strong field in between pulses in order to collect the particles charged by the corona.

Description of Research:

A laboratory, one-half scale test was conducted to compare a conventional ESP and the TEP. The resistivity of the dust was controlled by varying the humidity in the room. Test dust was supplied by a fluidized-bed feeder with a cyclone used to remove larger particles. Tests indicate that for dust resistivity of 1×10^{10} ohm-cm the two precipatators exhibited equal collection efficiencies. For 1×10^{12} ohm-cm, the TEP was about 95% efficient while the ESP was approximately 50%.

EFFLUENT RELEASE DATA Not addressed

Effluent Nuclides	Chemical Form	Removal Efficiency	Comment

Assessment Parameters:

Effectiveness:

Cost: Not addressed

Air Liquid Solid Residuals:

Energy Consumption: Not addressed

Comments by PI:

PI believes technique can be applied to higher resistivities as well. Advantage of this device is that its performance can be adjusted to changing dust resistivities.

CONTROL TECHNOLOGY RESEARCH SURVEY

Principal Investigators: Robert Reif

Location: Battelle - Columbus

Title of Research: Wet - Wall Electroinertial Unit

Sponsoring Agency
or : Industrial
Source of Funding

Cumulative Funding:
Start Date:

Projected Funding:
Completion Date:

Publications: EPA R 805148-01 (1978)

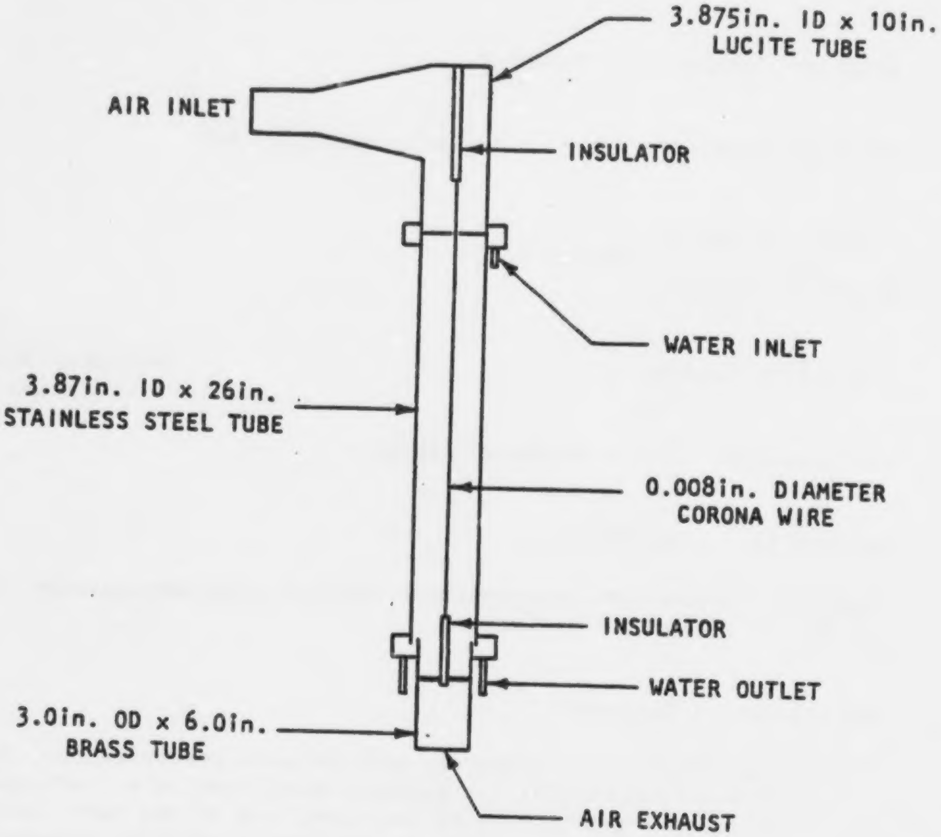
Control Technology/Process.

Combines inertial and electrostatic precipitating mechanisims with continual washing of collection surface.

Description of Research:

The unit consists of a concentric wire-in-tube precipitator. The charging wire is located axially in a stainless steel tube in a vertical orientation. Air enters tangentially at the upper end of the tube (through a duct with a flattened cross section) and acquires a rotating movement. When high voltage is applied to the wire, an ionizing corona discharge charges the dust in the air. As the air flows through the tube, the charged dust is driven to the wall by the radical electrical field (Figure C.1).

Water from the upper water inlet flows down the wall and flushes the precipitated dust into the water outlet at the lower end of the tube. The rotational movement of the air also induces rotational flow of the water, which assists in uniformly wetting the surface of the tube. Cleaned air is expelled from the tube's lower end.


3.875in. ID x 10in.
LUCITE TUBE
AIR INLET
INSULATOR
WATER INLET
3.87in. ID x 26in.
STAINLESS STEEL TUBE
0.008in. DIAMETER
CORONA WIRE
INSULATOR
WATER OUTLET
3.0in. OD x 6.0in.
BRASS TUBE
AIR EXHAUST

WET WALL ELECTROINERTIAL UNIT

DAMES & MOORE

FIGURE C.1

EFFLUENT RELEASE DATA

Effluent Nuclides	Particle Diameter	Removal Efficiency	Comment
	3-4um (MMD)	96-99%	Cotton dust

Assessment Parameters: Test unit largest flow was 800 CFM

Effectiveness:

Cost:

Air Liquid Solid Residuals: Liquid Waste

Energy Consumption: 500 Watts/1000 CFM

Comments by PI:

No problem with cleaning corona wire, tends to self-clean from vibration. ESPs operate at 50-500 watts/CFM, but with air velocity below 500 ft/min., whereas W.W.E. unit handles 2000-3000 ft/min. Another advantage - collection surface is 10 ft^2/1000 CFM, ESPs require 50-1000 ft^2/CFM. Advantage over baghouse is automatic cleaning and area required.

CONTROL TECHNOLOGY RESEARCH SURVEY

Principal Investigators: Albert "Woody" Baril

Location: USDA
SRRC
New Orleans, LA

Title of Research: Fluid Electrode Precipitator

Sponsoring Agency
or :
Source of Funding

Cumulative Funding:
Start Date:

Projected Funding:
Completion Date:

Publications: EPA R 805148-01 (1978)

Control Technology/Process: ESP with fluid used for collection electrode

Description of Research:

Developed in attempt to alleviate cleaning problems in ESP's. F.E.P. is designed for continuous operation. The fluid electrode precipitator consists of an array of electrodes in a casing to charge, direct, and collect fine dust. Tungsten wires serve as discharge electrodes for all units tested, auxiliary driving electrodes are charged metal plates or screens that can be inserted between the fluid electrodes, and the collection electrodes are formed by vertical tubes that release a laminar flow of water falling through the height of the casing.

The precipitator operation is quite simple. The falling columns of grounded water act as cylinders in cross flow and create vorticies for enhanced particle collection. Auxiliary electrodes and discharge electrodes can be positioned in arrays to direct charged dust into the grounded fluid. It is felt that the flow is deflected very little by drag forces at velocities up to 1000 ft/min. Fluid is deflected by electrostatic attraction but this can be compensated for by auxillary electrode placement. Prototype unit tested on cotton dust (3.6 um MMD), flows of 250-500 ft/min. Units of particle size would require intermediate flow tubes at approximately 1 ft. intervals of verticle fall to catch fluid, decelerate it, and return to laminar conditions.

EFFLUENT RELEASE DATA

Effluent Nuclides	Particle Diameter	Removal Efficiency	Comment
	1.5 - 10 u	60 - 81 %	Varies with flow, field
			strength, etc.
	Mass Efficiency	78 - 93 %	Varies with flow, field
			strength, etc.

Assessment Parameters:

Effectiveness:

Cost:

Air Liquid Solid Residuals:

Energy Consumption:

Comments by PI:

Once properly adjusted, an array of fluid electrodes can operate by continuously removing dust, with low maintainence.

Further research is being conducted to apply findings to large prototype units, to increase efficiences with deeper or more optimally selected electrode arrays, and to extend principles to other industrial situations requiring continuous fine dust collection.

CONTROL TECHNOLOGY RESEARCH SURVEY

Principal Investigators: Cooper, Wang, Anderson

Location: GCA Corp.
Burlington Road
Bedford, MA. 01730

Title of Research: Evaluation of 8 Novel Fine Particle Collection Devices (Braxton Sonic Agglomerator)

Sponsoring Agency or Source of Funding: EPA (Harmon)

Cumulative Funding:
Start Date:

Projected Funding:
Completion Date: 11/75

Publications: EPA 600/2-76-035

Control Technology/Process: Sonic Agglomeration

Description of Research:

An electromagnetically driven piston is used to produce sound intensities of approximately 165 dB in a chamber 0.75 m. in. in diameter and 4.3 m. in. in length, through which the contaminated gas flows. Water is added to this chamber at its top (stands with axis vertical) through sonicore nozzles said to deliver spray with droplets approximately 20um. The sound frequency and the chamber length are tuned to produce a standing wave 4.5 wavelengths long. The sound moves the particulate material with respect to the spray, and with respect to itself causing sonic agglomeration of particulates. The Braxton device is to be used for pretreatment of FMP particulate emissions to allow use of a control device such as a cyclone.

EFFLUENT RELEASE DATA

Effluent Nuclides	Particle Diameter	Removal Efficiency	Comment
	< .5	59.40%	Efficiencies are for agglo-
	.5 - 1.0	42.9	merator and cyclone
	1.0 - 2.0	47.1	
	2.0 - 3.0	55.3	
	3.2 - 5.5	88.2	
	5.5 - 9.2	87.8	
	9.2 - 14.1	96.9	

Assessment Parameters: Not Addressed

Effectiveness: Not Addressed

Cost: Not Addressed

Air Liquid Solid Residuals: Sludge

Energy Consumption: 6 hp/1000 CFM if cyclone is used
1.5 hp/1000 CFM if low energy scrubber is used
1.25 hp/1000 CFP for sonic agglomerator alone

CONTROL TECHNOLOGY RESEARCH SURVEY

Principal Investigators: C.H. Gooding, T.W. Sigmon, L.K. Monteith

Location: Research Triangle Institute
P.O. Box 12194
Research Triangle Park, N.C. 27709

Title of Research: Application of High-Gradient Magnetic Separation to Fine Particle Control

Sponsoring Agency or Source of Funding: EPA : Dennis C. Drehmel

Cumulative Funding:
Start Date: June '75

Projected Funding:
Completion Date: Sept 29, 1977

Publications: EPA - 600/2-77-230
Nov. 1977

Control Technology/Process: High-Gradient Magnetic Separation

Description of Research:

Theoretical bench-scale, and pilot scale research has been done on a High-Gradient Magnetic Separation system for removing fine particulate matter that has a relatively high magnetic susceptibility. Basically, the system consists of a canister packed with fibers of ferromagnetic material (such as stainless steelwool) which is subjected to a strong external magnetic field. Strong magnetic forces near the edges of the fibers result in very efficient collection of fine paramagnetic particles, thus particle laden gas is cleansed as it passes through the cannister. When the fiber matrix becomes loaded, the field is removed and the particles may be flushed from the cannister. This is essentially enhanced filtration; however, the void volume is typically much larger than in a conventional filter allowing high fluid velocity with relatively low pressure drops. There are possible applications of this technique to processes in the iron & steel industry and the ferralloy industry. Preliminary analysis indicates it is competitive with conventional controls. Operating costs are projected to be much less than that of wet scrubbers and less than ESPs. Capital costs may be somewhat higher. Efficiencies are indicated to be >99% for particle >1 um and >90% for submicron particles. Economic viability may depend on development of cyclical cleaning systems or continuous operation systems which have been demonstrated for liquid systems.

Advantages

The high throughput suggests smaller space requirements than electrostatic precipitators or baghouses. This could be important in any application, but especially perhaps in a retrofit situation. Stainless steel wool is a common, relatively inexpensive material which is resistant to high temperature and corrosive environments. The lack of any sparking mechanism should make the process amendable to dry, combustible environments with proper design precautions. Unlike many wet scrubber systems the HGMs process would not turn an air pollution problem into a water pollution problem. Even if water should be employed to assist in matrix cleaning, the quantity would be much less than in scrubber systems.

COMPARISON OF HGMS AND CONVENTIONAL TECHNOLOGY

Device	ESP	Scrubber	HGMS
Collection Efficiency, %	99.9	99.9	99.9
Flange-to-Flange Cost, $\$/m^3/s$	4042	2762	6653
$/CFM	1.91	1.30	3.14
Power Requirement, $kW/m^3/s$	3.2	24.2	2.2
hp/1000 CFM	2.0	15.3	1.4

All estimates are referred to clean gas at 343° C (650° F), -1.5 kPa (-6 in. H_2O) gauge, 11 percent water by volume.

COST ESTIMATES FOR LARGE IRON-BOUND SOLENOIDS APPLICABLE TO FINE PARTICLE CONTROL

Matrix Diameter	3.15 m	3.15 m
Matrix Length	15 cm	30 cm
Field Capability	0.4 T	0.4 T
Cost, (1977)	$320,000	$370,000

CONTROL TECHNOLOGY RESEARCH SURVEY

Principal Investigators: Tom E. Cturtnicek, H.H.S. Yu, C.M. Moscowitz

Location: Monsanto Research Corp
Dayton, OH.

Title of Research: Collection of Fine Particulates Using a Foam Scrubber

Sponsoring Agency
or
Source of Funding : EPA # 68-02-1453

Cumulative Funding:
Start Date:

Projected Funding:
Completion Date:

Publications: EPA R 805148-01 (1978)
EPA - 600/2-76-125

Control Technology/Process:

Foam Scrubber

Description of Research:

Gas stream contaminated with particulate matter is forced through a screen wetted with a surfactant solution. As the gas passes through the wet screen openings, foam is generated and the gas is enclosed in a mulitude of small bubbles. The distance which a particle must travel to reach a collection surface is now greatly reduced by the bubble enclosure. The foam passes through a main chamber of the scrubber where the particles are given time to migrate to collide with the bubble wall. As the foam is broken, particles retained on the bubble walls are collected in the surfactant liquid. Diffusion and sedimentation appear to be the main mechanisms of particle collection. Theory indicates that bubble diameter is of primary importance in collection effeciency. Bench-scale experiments were made using 4 different surfactants and 2 aerosols, DOP and polypropylene glycol. Flow rate was 2.5 ACFM. Collection efficiencies were seen to asymptotically approach 100% with an increase in residence time (< 1 um) (> 90% for gases). Residence times were changed by changing length of scrubber. This bubble diameter was 0.8 mm. Lower efficiencies were obtained for 3.9 mm bubbles. Tests were made on a 500 ACFM unit but with lower residence times (20 secs.) and lower efficiencies bearing out theory.

EFFLUENT RELEASE DATA

Effluent Nuclides	Particle Diameter	Removal Efficiency	Comment
	.1 to 1 um	> 90%	Residence times currently on
			order of 80 seconds should get
			higher efficiencies for longer
			residence times.

Assessment Parameters:

Effectiveness:

Cost: Projections made indicate less than ESP comparative to high energy wet-scrubber and fabric filter.

Air Liquid Solid Residuals:

Energy Consumption: Operating costs - greater than ESP, varies with surfactant makeup liquid and pressure drop on order of 7 inches H_2O

Comments by PI:

Calculations made by George Lamb at Princeton indicate 99% efficiency could be obtained (.5um) for 100 seconds residence time using .25 mm bubbles.

Comments by Dames & Moore:

500 cfm unit was used on fly ash from Nucla, CO. plant. No temperature information was found.

CONTROL TECHNOLOGY RESEARCH SURVEY

Principal Investigators: R. Hegarty, L.T. Shannon

Location: Midwest Research Institute
425 Volker Boulevard
Kansas City, MO. 64110

Title of Research: Evaluation of Sonics for Fine Particle Control

Sponsoring Agency or Source of Funding: EPA
Industrial Environmental Research Laboratory
Research Triangle Park, NC.
Project Officer: Dennis Drehmel

Cumulative Funding:
Start Date:

Projected Funding:
Completion Date:

Publications: Evaluation of Sonics for Fine Particle Control
EPA Report No. 600/2-76-001
Contract 68-02-1324 Task 24

Control Technology/Process:

Agglomeration of fine particulates through application of sonic energy.

Description of Research:

This study was a literature search which reviewed theoretical, laboratory, pilot-scale, and full-scale evaluations of sonic agglomeration from both U.S. and foreign sources. A comparison of energy usage between sonic agglomerators and other conventional fine particle collection systems is made which indicates that sonic agglomeration requires energy consumptions of 5-20 hp/1000 CFM which is not competitive with existing conventional systems. The research also indicated the following: 1) sound intensities of 150-160 dB would be required for industrial applications; 2) highly polydisperse aerosols are easier to agglomerate than monodisperse aerosols; and 3) a spray of water into low concentration aerosols improves agglomeration. The efficiency of agglomeration decreases markedly below 2-5 g/m^3 and above 100 g/m^3.

EFFLUENT RELEASE DATA Not Addressed

Effluent Nuclides	Particle Diameter	Removal Efficiency	Comment

Assessment Parameters:

Effectiveness: Collection efficiencies improved (for cyclone systems) from 70% initial to 90% with sonics.

Cost: Not addressed

Air Liquid Solid Residuals: Particulates, particulates plus water if spray is used.

Energy Consumption: 5-20 hp/1000cfm

Comments by PI:

Technique not promising for controlling fine particulates. Gain over conventional methods is marginal at best and cost would be higher due to energy usage; might be useful technique for controlling highly toxic emissions where the ultimate in control is required.

Comments by Dames & Moore:

The technique appears costly, however, its ability to enhance collection efficiency has been demonstrated. The literature search by the authors covered its application to cyclones only in the field. Using sonics with ESP could be an approach to highly toxic emissions if sound and cost problems can be resolved.

CONTROL TECHNOLOGY RESEARCH SURVEY

Principal Investigators: D.T. Shaw, S. Patel, M.T. Cheng, J. Wegrzyn

Location: State University of New York at Buffalo (SUNYAB)
Laboratory for Power and Environmental Studies
4232 Ridge Lea Road, Buffalo, N.Y. 14226

Title of Research: Application of Acoustic Agglomeration for Fine Particulate Emission Control.

Sponsoring Agency or Source of Funding: Electronic Power Research Institute (EPRI)
3412 Hillview Avenue
Palo Alto, CA. 94304
Project Manager: Walter Piulle

Cumulative Funding:
Start Date:
Projected Funding:
Completion Date:

Publications: FP-887 Research Project 539-1
Final report, August, 1978

Control Technology/Process:

Agglomeration of fine suspended particulates with coarser particulates through application of sonic energy (orthokinetic interaction).

Description of Research:

This was a theoretical study, supplemented by laboratory experiments, to determine the feasibility of utilizing acoustic agglomeration to augment electrostatic precipitation for fine particulate control from pulverized-coal-fired utility boilers. Sonic agglomeration constants were determined for polystyrene latex, dioctyl phthalate (DOP), and Fe_2O_3 particles. The optimum sonic frequency was determined to be approximately $10KH_z$. Agglomeration was enhanced by the use of standing waves, and by a spray injected into the agglomeration chamber. The agglomeration rate increased with the number of particles larger than 2 um in diameter, and varied as the square root of the acoustic intensity. EPRI's conclusion was that the intense sound levels (150dB), and the power required (1hp/cu.ft./min.) did not make this approach economically attractive for current power station use.

EFFLUENT RELEASE DATA Not Addressed

Effluent Nuclides	Particle Diameter	Removal Efficiency	Comment

Assessment Parameters:

Effectiveness: Collection efficiency not addressed.

Cost: Not directly addressed except through energy usage.

Air Liquid Solid Residuals: Particles, particles plus water when spray utilized

Energy Consumption: 1 hp/1000 cu.ft./min. or 1000 hp for power station with gas flow rate of 10^6 cu ft/min.

Comments by PI:

More research needed at frequencies of a few hundred cycles per second when hydrodynamic forces are used.

Comments by Dames & Moore:

This was a limited laboratory test. Size fraction studied was .085/10um, fairly monodisperse ($\sigma g \cong 1.5$) with experimental aersols. Limited conclusions should be drawn. The report does not indicate potential problems of cost and noise for the experimental configuration employed.

CONTROL TECHNOLOGY RESEARCH SURVEY

Principal Investigators: K.P. Ananth & L.J. Shannon

Location: Midwest Research Institute
425 Volker Boulevard
Kansas City, MO. 64110

Title of Research: Evaluation of Turbulent Agglomeration for Fine Particle Control.

Sponsoring Agency or Source of Funding: EPA Office of Research and Development
Industrial Environmental Research Laboratory
Research Triangle Park, NC 27711
Project Officer: D.C. Drehmel

Cumulative Funding:
Start Date:
Projected Funding:
Completion Date:

Publications: EPA - 600/2-76-066

Control Technology/Process:

Agglomeration of fine particulates through application of turbulence.

Description of Research:

This study was a literature search wnich considered both theroetical and experimental aspects of enhancement of fine particle agglomeration by application of turbulence to the flow stream. Key parameters affecting agglomeration through turbulence were identified to be 1) particle size, 2) particle concentration, 3) rate of dissipation of turbulant energy and, 4) viscosity. Agglomeration decreases as particle size decreases so that turbulence does not significantly increase agglomeration of particles less than 0.2um in diameter. However, the coagulation constant of 0.5um particles is increased by a factor of 10 and the constant of a 1 um particle is increased by a factor of 100. The energy required is approximately 40hp/1000 cu. ft.

EFFLUENT RELEASE DATA Not Addressed

Effluent Nuclides	Particle Diameter	Removal Efficiency	Comment

Assessment Parameters:

Effectiveness: Not estimated except through coagulation constants.

Cost: Not estimated

Air Liquid Solid Residuals: Particulates

Energy Consumption: 40 hp/1000 cu. ft.

Comments by PI:

Turbulent agglomeration is not useful for fine particulates if an external source of turbulence must be supplied since the energy required is high. If turbulence already exists in a collection system, it may sometimes be taken advantage of.

Comments by Dames & Moore:

Might be useful in conjunction with other mechanisms such as filters or scrubbers to enhance agglomeration via orientation of fans, baffles without additional external sources of energy.

CONTROL TECHNOLOGY RESEARCH SURVEY

Principal Investigators: K.P. Ananth & L.J. Shannon

Location: Midwest Research Institute
425 Volker Boulevard
Kansas City, MO 64110

Title of Research: Evaluation of Thermal Agglomeration for Fine Particle Control

Sponsoring Agency or Source of Funding: EPA Office of Research and Development
Industrial Environmental Research Laboratory
Research Triangle Park, NC 27711
Project Officer: D.C. Drehmel

Cumulative Funding:
Start Date:

Projected Funding:
Completion Date: 9/12/74

Publications: EPA - 600/2-76-067
March, 1976

Control Technology/Process:

Thermal agglomeration of fine particles

Description of Research:

Theroetical and experimental studies indicate that the overriding disadvantage of thermal agglomeration with regard to industrial gas cleaning applications is the long residence time required to achieve significant particle growth (Industrial applications require residence times of 10 seconds or less). Experiments by Derjaguin & Vlasenko with 0.1 - 0.3μm particles achieved decreases in size by 2 to 3 times, but residence times were on the order of 100 minutes.

The main parameters which can be used to enhance the rate of thermal agglomeration are particle size and concentration, gas composition and gas temperature. Temperature and composition are usually not useful parameters because they are characteristic of the effluent stream. Seeding the aerosol to change size distribution and concentration and thereby increase the agglomeration rate was thought to be effective at an early stage of the agglomeration cycle but would rapidly lose effectiveness. The conclusion was that this was not a viable approach.

References: 1) Derjaguin, B. and Vlasenko, G.
Dokl. Akad. Nauk SSSR, 63,155 (1948)

2) Whytlaw-Gray, R. and H.S. Patterson
Smoke
Edward Arnold, London (1932)

CONTROL TECHNOLOGY RESEARCH SURVEY

Principal Investigators: K.P. Ananth & L.J. Shannon

Location: Midwest Research Institute
425 Volker Boulevard
Kansas City, MO. 64110

Title of Research: Evaluation of Magnetics for Fine Particle Control

Sponsoring Agency or Source of Funding: EPA Office of Research and Development
Industrial Environmental Research Laboratory
Research Triangle Park, NC 27711
Task Officer: D.C. Drehmel Contract 68-02-1324, Task 26

Cumulative Funding:
Start Date:
Projected Funding:
Completion Date:

Publications: EPA - 600/2-76-133
Evaluation of Magnetics for Fine Particle Control

Control Technology/Process:

Agglomeration, separation, and collection of particulates through the application of magnetic fields.

Description of Research:

Theoretical calculations show that magnetic fields alone are probably not practical as a primary removal mechanism due to the high particle velocities and large magnetic fields required. Theoretical calculations were also employed to indicate that agglomeration through the application of magnetic forces is also impractical due to the long residence times required (10-1000 sec. for particle concentrations of 2-23 g/m^3), the potentially large magnetic field system required (46-229M for 100,000 cfm flow) if shorter residence times were attempted, and due to the necessity of using a particle charging system to prevent repulsion of uni-polar particles, and the necessity for also using a separate collection system. The authors feel that the technique could be useful for separation of high permeability materials in industrial gas streams. Further research on efficiency and cost need to be conducted.

EFFLUENT RELEASE DATA Not Addressed

Effluent Nuclides	Particle Diameter	Removal Efficiency	Comment

Assessment Parameters:

Effectiveness: Not addressed in quantitative terms

Cost: Not addressed

Air Liquid Solid Residuals: Particulate

Energy Consumption: Not evaluated

Comments by PI:

Possible future use for separation for specific industrial gas streams (high permeability streams). More research needed on cost and efficiency as a function of permeability, entrainment, filament diameter, and pressure drop. Energy usage should also be evaluated.

Comments by Dames & Moore:

Laboratory tests at RTP should answer many of the above questions. Field tests are also required. Advancements in superconductivity magnets could improve this technique to make it more feasible.

CONTROL TECHNOLOGY RESEARCH SURVEY

Principal Investigators: Joseph D. McCain

Location: Southern Research Institute
2000 4th Ave
South Birmingham, Ala. 35205

Title of Research: Evaluations of Novel Particulate Control Devices

Sponsoring Agency or Source of Funding: EPA
Dale L. Harmon

Cumulative Funding:
Start Date:

Projected Funding:
Completion Date:

Publications: EPA - 600/7-78-093 June 1978
Interagency Energy/Environment R&D Program Report

Control Technology/Process:

Rexnord Gravel Bed Filter

Description of Research:

The device is basically a dry filtration technique using a fixed bed of fine gravel. The filter unit can be cleaned. Tests were made to control the emissions from clinker coolers on 2,500-tons/day Portland Cement kilns. At any one time seven of the eight modules are in use while one is being cleaned. Overall mass efficiencies and fractional efficiencies were detemined while in normal operation. The results do not seem very reliable, but in any case, collection efficiencies were poor (>80%) and at times even negative for particles >3um. Efficiencies <90% are reported for particles <3um. Negative efficiencies were thought to result from the breaking up of agglomerated particles during the cleaning of the beds. Pressure drop resulting from the system was approximately 10 inches of water.

COMMENT

The collection efficiency of the Rexnord gravel bed filter, determined by conventional (method 5) techniques on a source producing particulate having a mass median diameter of about 200 um ranged from 95% to 98% during three days of testing throughout which the collector was not operating in an optimum mode. Overall efficiencies determined from cascade impactor data during a second two-day test series were found to be 99.3% and 99.7%. The system pressure drop in the first test series ranged from 11.6 to 17.6 cm w.c. while during the second test series the system pressure drop ranged from 9.6 to 14 cm w.c. Measured fractional efficiencies were about 50% at 0.04 um, zero or negative over the size interval from about 0.08 um to 1.0 um, approximately zero at 1 um, 30% at 2 um, and about 97.5% at 5 um. The system energy usage during the tests was approximately 1780 JOULES/SCM (47.7 BTU.1000 SCF) at a pressure drop of 11.8 cm (4.7 inches) w.c.

CONTROL TECHNOLOGY RESEARCH SURVEY

Principal Investigators: 1) E.W. Schmidt, J.A. Gieseke
2) P. Getlend, T.W. Lugar,
D.A. Furlong

Location: 1) Battelle-Columbus
2) Envirotech Corp.

Title of Research: Filtration Theory for Granular Beds

Sponsoring Agency
or :
Source of Funding

Cumulative Funding:
Start Date:

Projected Funding:
Completion Date:

Publications: APCA Feb. 78 Vol. 28, No. 2

Control Technology/Process:

Granular Bed Filtration

Description of Research:

Mainly theoretical, a filter efficiency equation was developed. Lab testing was done on beds of polyethylene beads and quartz gravel. Bed depth of 15.24 cm., and velocities at 15.24 cm./sec., 47.75 cm./sec., 101 cm./sec. It appears from the results that the theory is substantiated. However near zero % efficiencies were recorded in the 0.1 to 1 um range for all velocities. High efficiencies were achieved for particles >2um.

Advantages of system are high gas temperatures allowed: 1500°F for metal structures and higher for ceramic.

May be more compact than ESPs or Baghouses.

CONTROL TECHNOLOGY RESEARCH SURVEY

Principal Investigators: Jeff Alexander

Location: E.F.B. Inc.
78 Cummings Park
Woburn, MA 01801

Title of Research: Electrified Filter Bed

Sponsoring Agency
or :
Source of Funding

Cumulative Funding:
Start Date:

Projected Funding:
Completion Date:

Publications: EPA - 600/7-78-178

Control Technology/Process:

Charged granular filtration bed

Description of Research:

Polluted gas enters through gas inlet and passes through a granular pre-filter bed, which acts principally as a mechanical collector employing inertial collection mechanisms which remove supermicron particles. The remaining particulate, mostly submicron, is charged in an efficient corona ionizer operated at low power. The charged particulate is finally passed through a second electrified bed where the remaining particulate is deposited on the filter media by electrostatic forces. The filter media consists of material which need only be semi-insulating to be effective; sand, crushed slate or glass, glass beads and absorbing clay granules have been successfully tested. The media is retained between grounded louvered and perforated plate electrodes with a high voltage electrode between them. The electrodes are maintained at a high voltage by external power supplies. The electrical field thus formed permeates the bed and polarizes the filter media particles, which act as collector sites for the charged particulate. During operation of the system, the granules become coated with the collected particulate as they flow continuously through the system. EFB tested unit on flyash from power plant (600-1000 acfm) 1"-2" H_2O P, 275-375°F. GCA tested unit for EPA on asphalt emissions. Temp. 140°F, 300-400 acfn.

EFFLUENT RELEASE DATA

Effluent Nuclides	Particle Diameter	Removal Efficiency	Comment
	MMD of 2um	98.7-99.9	Flyash
	MMD of 1 um	98.57 avg of 6 runs	Asphate emissions (90% <um)

Assessment Parameters:

Effectiveness:

Cost: Capital Cost $1-3.50/ACFM (1969 dollars)

Air Liquid Solid Residuals:

Energy Consumption: Annualized Cost $0.28-0.89/10^6 ACFM (1969)

Comments by PI:

EFB has marked avantages over other control devices such as ESPs or baghouses. Its ultra high collection efficiency results from high amounts of collection surface area afforded by the granular bed collection. It is highly rugged, and corrosion resistant. Comments by GCA on EPA report were that the conventional venturi scrubber would require 70" H_2O drop to attain the same efficiency at 8 times the operating cost of the EFB.

Comments by Dames & Moore:

Maximum Temperature 1500°F

CONTROL TECHNOLOGY RESEARCH SURVEY

Principal Investigators: K.P. Ananth & L.J. Shannon

Location: Midwest Research Institute
425 Volker Boulevard
Kansas City, MO. 64110

Title of Research: Evaluation of Electrofluidized Bed

Sponsoring Agency or Source of Funding: EPA Office of Research and Development
Industrial Environmental Research Laboratory
Research Triangle Park, NC 27711
Project Officer: D.C. Drehmel

Cumulative Funding:
Start Date:

Projected Funding:
Completion Date:

Publications: EPA - 600/2-76-040

Control Technology/Process:

Electrofluidized bed collection of fine particles by electrostatic and inertial forces.

Description of Research:

This is a theroetical analysis of the EFB process. Maximum predicted overall collection efficiencies ranged from 96% for 1um particles to 85% for a 0.5um particle in the single pass 1 ft. bed for a fluidization velocity of 15cm/sec., an availability factor of 0.1, and an individual collection diameter of 100um. Aerosol particles were assumed to be charged to saturation in a field of 2.5 X 10^5 v/m. Bed particles were assumed to be charged to saturation in a field of 5 X 10^5 v/m. Predicted collection efficiencies were found to decrease with 1) decreasing aerosol size, 2) increasing superficial velocity, 3) decreasing bed availability, and 4) increasing size of fluid bed particles. Bed age and dynamics are also expected to play an important role in collection and are not well enough understood for complete quantitative treatment. A literature search by the authors indicated that >90% collection efficiency is not likely to be obtained in a single pass bed due to inherent operational problems.

EFFLUENT RELEASE DATA Not Addressed

Effluent Nuclides	Chemical Form	Removal Efficiency	Comment

Assessment Parameters:

Effectiveness: 96% for 1um, 85% for 0.5um for conditions stated

Cost: Not addressed

Air Liquid Solid Residuals: Particulates

Energy Consumption: Not addressed

Comments by PI:

Staging of beds may allow higher collection efficiencies.

Comments by Dames & Moore:

The technique is most applicable to low flow emissions according to authors data.

CONTROL TECHNOLOGY RESEARCH SURVEY

Principal Investigators: D.L. Reid and L.M. Browne

Location: Battelle Northwest
P.O. Box 999
Richland, Washington 99352

Title of Research: Electrostatic Capture of Fine Particles in Fiber Beds

Sponsoring Agency or Source of Funding: EPA - RTP
D.C. Drehmel

Cumulative Funding:
Start Date: 6/73

Projected Funding:
Completion Date: 6/75

Publications: EPA - 600/2-76-132
May 1976

Control Technology/Process:

Fiber bed filtering of charged particles

Description of Research:

Efficient removal of charged submicrom particles from flowing gas streams with a bed consisting of fibers having a high dielectric constant was demonstrated experimentally. Particles are charged via a corona-charging section and collected in beds of teflon fibers or polypropylene. As particle size decreases and resistivity increases, the efficiency of ESPs is significantly reduced. Tests using this apparatus were made on particles between .06 and .7 microns and with resistivities of 10^5 to 10^{12} Ohm-cm. Efficiencies >90% were found for flow rates of 300 ft/min (24" diam. pipe). Efficiency increases linearly with decreasing flow rate (99% for 100ft./min. & $100 mg/m^3$ concentration). Pressure drops were generally low (< 1in H_2O) (Avg .5"). For industrial applications, particle characteristic (resistivity and concentration) as well as the control system operating conditions are necessray to optimize efficiency, cleaning frequency and area of filter bed. Though only submicron particles were tested, it was suggested that efficiencies should be greater for larger particles. Also note that temperatures of gas were anticipated to be <300°F and then with Teflon fibers.

Dames & Moore Comment:

Current work in improving high temperature preformance of fiber filters may extend useful temperature range of this control technique.

CONTROL TECHNOLOGY RESEARCH SURVEY

Principal Investigators: 1) Dennis Helfritch
2) Teorman Ariman

Location: American Precision Industries Inc.
Notre Dame

Title of Research: Electrostatic Filtration and the Apitron/Design & Field Performance

Sponsoring Agency or Source of Funding:

Cumulative Funding:
Start Date:

Projected Funding:
Completion Date:

Publications: EPA R 805148-01

Control Technology/Process:

Baghouse filtration augmented by electrostatic charge.

Description of Research:

A precipitator section is added before the baghouse. Gas enters precipitator tubes where particulate is charged and where most is deposited. Flows from tubes into bags where final filtration takes place. When no high voltage is applied, behaves as conventional cleaning pulse type baghouse. When voltage is applied filter resistance decreases. This decrease in resistance continues as voltage is increased because particles become more highly charged and because more particulate is deposited on the metal tube. Pilot-plant unit (1000CFM) tested at Asphalt, Gypsum Rock, Phosphate, Electric Steel Furnace, Aspestos, and Cement Kiln sites. Performance is compared to parallel operating baghouses. Air/cloth ratios are from 4 to 7 times higher for Apitron and collection efficiencies were improved (reduction in emissions by 1/2 to 1/10 of particulate on a weight basis). Another result is the demonstrated increases in filtration capacity per square foot of fabric when charged particulate is collected. This occurs because the particulate deposits on the fabric on a more open, loosely packed structure. The structure is more permeable and hence, allows a greater filtration rate.

CONTROL TECHNOLOGY RESEARCH SURVEY

Principal Investigators: C.W. Lear, W.F. Krieve, J.M. Bell

Location: TRW Defense and Space Systems Group
One Space Park
Redondo Beach CA. 90278

Title of Research: Charged Droplet Scrubber (CDS) for Fine Particle Control: 1) Lab Study, 2) Pilot Plant Study

Sponsoring Agency or Source of Funding: EPA
: Dale Harmon

Cumulative Funding:
Start Date: 7/74

Projected Funding:
Completion Date: 6/76

Publications: EPA - 600/2-76-249a Sept 1976
EPA - 600/2-76-249b

Control Technology/Process:

Uses electrically charged water droplets accelerated through an electric field, to remove particulate from a gas stream.

Description of Research:

The CDS is a device that uses electrically sprayed water droplets, accelerated through an electric field to remove particulate material from a gas stream. Extensive theoretical analysis has been preformed, along with bench-scale and pilot plant experimentation. In the device fresh water is raised from ground potential to high voltage (40KV) by flowing through a long electrical resistance path in the form of an insulating tubing. The water is then introduced into a hollow electrode which contains a series of hollow, elongated spray tubes. Emerging at the tips of these spray tubes, the water encounters a high electric field force. Droplets are formed by the joint action of electrical and surface tension forces. The droplets are highly charged and move swiftly through the scrubbing volume under the influence of the electric field between the electrode and the collecting walls. The large relative motion between droplets and particulate enables the small particles to overcome aerodynamic forces which would normally sweep them around the droplet of water with the flow stream. This leads to enhancement of particulate collection by agglomeration and by electrical interaction. Improvement of overall efficiency is claimed as compared to conventional scrubbing. Zinc-oxide fume was used in the bench-scale test and emissions from a coke oven battery in the pilot plant test. Pilot plant particles were 42% by weight < 1um, 96% < 10um. Temperature of gas was 400°F. Capacity of pilot unit was 28,500 acfm.

EFFLUENT RELEASE DATA

Effluent Nuclides	Particle Diameter	Removal Efficiency	Comment
	.1um	78 - 80%	Nominal Diameter (Bench Test)
	1um	70 - 90%	Geometric Mean Dia after (Bench)
		95%	Test Overall (Bench Test)
	.4 - 1.5	Up to 95%	Mean diameter (Pilot Plant Test)

Assessment Parameters:

Effectiveness:

Cost:

Air Liquid Solid Residuals: Particulate matter returned in liquid waste

Energy Consumption: 0.8 to 1.2 watts/acfm
0.8 to 1.0 gal/1000 acfm

Comments by PI:

Other parameters being equal, the CDS shows a lower specific volume and lower specific power than other control devices. When water usage at flue pressure drop is a basis of comparison, the CDS shows competitiveness. CDS devices have unusual effectiveness in the .1 to 1 um range compared to conventional ESPs or wet scrubbers.

Comments by Dames & Moore:

Table C-1 presents cleaning efficiencies for 0.1 and 1.0 micron particles for a CDS with one to four stages. Table C-2 compares the CDS with a high performance ESP for four important performance parameters.

TABLE C-1

CDS Performance for Sub-Micron Particle Removal*

Number Of Stages	Specific Power ($watt/m^3/hr$)	Specific Water Flow Rate ($liter/m^3$)	Collection Area ($m^2/m^3/hr$)	Cleaning Efficiency Particle Size 0.1 Micron	1.0 Micron
1	7.9×10^{-2}	2.7×10^{-2}	1.2×10^{-3}	40%	70%
2	1.58×10^{-1}	5.4×10^{-2}	2.4×10^{-3}	64%	91%
3	2.37×10^{-1}	8.1×10^{-2}	3.6×10^{-3}	78%	97%
4	3.16×10^{-1}	1.08×10^{-1}	4.8×10^{-3}	87%	99%

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* For 0.125 meter collector spacing, a gas stream velocity of 1.0 m/sec and particle loadings int the range of 50 to 1600 mg/m^3.

TABLE C-2

CDS vs ESP - Performance Comparison[1]

Parameter	CDS (3 Stages)	High Performance Electrostatic Precipitator
Specific Water (liter/m^3)	0.081[2]	N/A
Specific Power (watts/m^3/hr)	0.24	0.35
Collection Area (m^2/m^3/hr)	0.0032	0.033
Residence Time (m^3/m^3/hr)	0.0003	0.003

---

[1] Removal Efficiency - approx. 78% less than .5 micron
- approx. 95% overall

[2] Electrode flow only. Total water requirement is approximately 2.5 times this value for continuous wall wash.

CONTROL TECHNOLOGY RESEARCH SURVEY

Principal Investigators: Douglas W. Cooper, Richard Wang, Daniel Anderson

Location: GCA Corp.
Burlington Road
Bedford, MA. 01730

Title of Research: Evaluation of 8 novel Fine Particle Colection Devices

Sponsoring Agency or Source of Funding: EPA
: Dale Harmon

Cumulative Funding:
Start Date:

Projected Funding:
Completion Date: 11/75

Publications: EPA - 600/2-76-035
Feb. 1976

Control Technology/Process: University of Washington Electrostatic Droplet Scrubber
Developed by Dr. Michael Pilut
University of Washington

Description of Research:

The scrubber consists of two spray chambers, one with counter current flow, and/one with current flow. The scrubber is electrostatically augmented by charging of the droplets and the particulates to opposite polarities using inductive charging and corona charging, respectively.

Scrubbers were tested at flow rates of 140 cfm and 700 cfm.

It is conceivable that an existing spray scrubber could be modified to make it an electrostatic spray scrubber.

Applications: Coal fired boilers, lead sinter crushers, phosphate rock dryers, electric arc furnaces, carbon black manufacturing refineries, paper mills.

EFFLUENT RELEASE DATA

Effluent Nuclides	Particle Diameter	Removal Efficiency	Comment
	.5 to 4um	> 95%	
	.3 to .5	> 85%	

Assessment Parameters:

Effectiveness:

Cost: Not Addressed

Air Liquid Solid Residuals: Particulate in waste water

Energy Consumption: Water consumption is 15 gal./1000ft^3
(Higher than most scrubbers)
Approx. 0.8hp./1000acfm

Comments by PI:

Comments by Dames & Moore:

Efficiency is predicted to decrease as gas temperature increases. Increasing water consumption rate increases efficiency.

CONTROL TECHNOLOGY RESEARCH SURVEY

Principal Investigators: Douglas W. Cooper, Richard Wang, Daniel Anderson

Location: GCA Corp.
Burlington Road
Bedford, MA. 01730

Title of Research: Evaluation of 8 novel Fine Particle Control Devices (Pentapure Scrubbers)

Sponsoring Agency or Source of Funding: EPA
Dale Harmon

Cumulative Funding:
Start Date:

Projected Funding:
Completion Date: 11/75

Publications: EPA - 600/2-76-035

Control Technology/Process: Similar to venturi type scrubber. More collisions occur as droplets/particles strike the surface. A slurry forms as they run off.

Description of Research:

Dust-laden air is mixed with a water spray. The mixture accelerates in a converging section causing particle-droplet collisions and perhaps particle-particle collisions. The mixture is directed on a jet at an inpingement surface and undergoes rapid deceleration. The air exhaust contains any uncaptured particles and droplets.

Applications: Those where venturi scrubber is employed.

No indication of gas flow capabilities (at throat was 20,000 cfm). There are indications that the higher the temperature the lower the efficiency.

EFFLUENT RELEASE DATA

Effluent Nuclides	Particle Diameter	Removal Efficiency	Comment
	3.0	43.8	
	1.75	44.1	
	0.98	15.8	
	0.62	-38.5	
	0.25	-30.0	
	> 4um	approaches 99%	

Assessment Parameters:

Effectiveness:

Cost:

Air Liquid Solid Residuals: Slurry

Energy Consumption: 1.6 hp./1000cfm

Comments by PI:

Possible explanation of negative efficiencies: agglomeration, deagglomeration, or other change in particle size distribution without increase or decrease in total mass; production of particles, as by spray; random data errors on the vicinity of zero efficiency.

Comments by Dames & Moore:

CONTROL TECHNOLOGY RESEARCH SURVEY

Principal Investigators: T. Dembinsky, J. F. Vicard

Location: Chemco Air Pollution Control
Envirotech Corp.
New York, NY

Societe Lab
Lyon, France

Title of Research: A Low Energy, High Velocity Electrostatic Precipitator-The Electrodynamic Venturi Scrubber

Sponsoring Agency
or :
Source of Funding

Cumulative Funding:
Start Date:

Projected Funding:
Completion Date:

Publications:

Control Technology/Process:

Combinaion wet venturi scrubber and ESP
(EDV-Electrodynamic Venturi Scrubber)

Description of Research:

Hot dust laden gases are first cooled and partially saturated with H_2O. Next gases enter EDV scrubber thru venturi throat where expansion and condensation simultaneously occur. The dust particles in the gas stream act as condensation nuclei and are wetted and covered with an envelope of H_2O. At the same time they are subjected to the electrical field created by a high voltage electrode inserted in the center of the venturi throat. The electrode augments the capacity of the venturi scrubber to capture particles as they are carried thru the EDV unit. The electrode is designed to create a negative corona effect; particles leaving venturi throat are negatively charged. A short distance from the end at the electrode, a spray nozzle introduces a screen of larger water droplets positively charged by induction. Particles are collected by the screen of droplets as a result of impaction and electrostatic attraction. Particles and droplets are separated from gas in liquid stream. Residual droplets are removed by another section before discharge.

Pressure drops: 2 - 4" H_2O
Typical Gas Vol: 1 million cfm

EFFLUENT RELEASE DATA

Effluent Nuclides	Particle Diameter	Removal Efficiency	Comment
	.6 micron	92 - 95%	Test on dioctyl phthalate aerosol fumes from wet blast cupola were first introduced into a conventional scrubber - 98.2% of particles (coarse) were removed. The remainder entered EDV and 96.7% of remaining fine particles were removed. (No indication as to size distribution of fractional efficiency.)

Assessment Parameters:

Effectiveness:

Cost:

Air Liquid Solid Residuals: Liquid waste

Energy Consumption: Comparison is given between ESP and EDV. Claimed that ESP uses 1.4 times as much power.

Comments by PI:

Operating in several commercial installations in France. Available in USA through Chemco

Comments by Dames & Moore:

CONTROL TECHNOLOGY RESEARCH SURVEY

Principal Investigators: Douglas W. Cooper, Richard Wang, Daniel Anderson

Location: GCA Corp.
Burlington Road
Bedford, MA. 01730

Title of Research: Evaluation of 8 novel Fine Particle Control Devices (Dynactor Scrubber)

Sponsoring Agency or Source of Funding: EPA
Dale Harmon

Cumulative Funding:

Projected Funding:

Start Date:

Completion Date: 11/75

Publications: EPA - 600/2-76-035
EPA - 650/2-74-083a

Control Technology/Process:

Wet scrubber employing water spray which serves as air mover and scrubber simultaneously.

Description of Research:

Water entering the system from a nozzle under pressure of 140-200 psi is atomized into thin films and droplets of average thickness or diameter of less than 1/64". This liquid diffuses or expands into a reaction chamber causing air or gas to be aspirated by being trapped within the moving shower of films and particles. The resulting mixture of fluid travels down a reaction column into a separation reservoir. It is claimed that the Dynactor has the ability to aspirate up to 4800 standard volumes of gas per volume of motive liquid. Venturi eductors will not aspirate more than 100 volumes of gas per volume of motive liquid.

Potential Applications: Same as scrubber technology - metallurgical operations, refineries, paper mills and industries which have fine, sticky, or liquid emissions.

A two-stage device was tested at 1000cfm.
Devices may be connected in parallel.
50,000 cfm device available with plans for 10^6 cfm unit
Tested at 200°F - hotter gases may be more difficult to scrub without pre-chilling.

EFFLUENT RELEASE DATA

Effluent Nuclides	Particle Diameter	Removal Efficiency	Comment
	Total	96.04	
	2.5-4.0um	98.37	
	1.3-2.5um	93.00	
	0.8-1.3um	75.4	
	.54-.8	27.4	
	< .54	47.4	

Assessment Parameters:

Effectiveness:

Cost: Not Addressed

Air Liquid Solid Residuals: Particulate in waste water as from any scrubber

Energy Consumption: 3.3 hp/1000cfm water pumps

Comments by PI:

Maker claims energy requirements are "considerably lower than for conventional jet or venturi systems".

Comments by Dames & Moore:

Poor performance in sub-micron range.

CONTROL TECHNOLOGY RESEARCH SURVEY

Principal Investigators: Douglas W. Cooper, Richard Wang, Daniel Anderson

Location: GCA Corp.
Burlington Road
Bedford, MA. 01730

Title of Research: Lone Star Steel Steam-Hydro Scrubber

Sponsoring Agency or Source of Funding: EPA
Dale Harmon

Cumulative Funding:
Start Date:

Projected Funding:
Completion Date: 11/75

Publications: EPA - 600/2-76-035
EPA - 650/2-74-028

Control Technology/Process:

High-speed steam and water scrubbing system

Description of Research:

The scrubber uses high pressure steam to move gas through the system. Rapidly moving steam entrains gas, particles, and droplets. Particles collect on droplets through impaction, diffusion and condensation of the steam. Once particles have collected on droplets, the drop/particle mixture is caught in cyclones immediately downstream from the scrubber mixing section. Energy required to move the gas through the system is not supplied by fans or pumps but by steam produced in boilers or economizers operating on the waste heat of the process.

Existing Applications: Open hearth furnaces, cupolas, iron ore kilns, paper mills, sinter plants, ammonium nitrate fertlizer plants, copper smelters. Possible: BOFs, EAFs, lime and cement kilns, municipal incinerators.

Volume Flow Rates: 4000 to 300,000 scfm
Temp: Highest temperatures industrial gases may be cleaned

EFFLUENT RELEASE DATA

Effluent Nuclides	Particle Diameter	Removal Efficiency	Comment
Mass median aero dynamic	1.8um	99.9%	Avg. collection efficiency
	> .3	> 99%	
	.05	70%	Min. effect at this diameter

Assessment Parameters:

Effectiveness:

Cost: Not Addressed

Air Liquid Solid Residuals: Waste water sludge from cyclones

Energy Consumption: Approx. 200-300 hp/1000 scfm
(Waste Heat)

Comments by PI:

Power consumption is an order of magnitude greater than an ejector venturi scrubber, if fuel must be purchased to make steam - not an economic alternative to such systems as fabric filtration or ESPs.

Comments by Dames & Moore:

CONTROL TECHNOLOGY RESEARCH SURVEY

Principal Investigators: Joseph D. McCain

Location: Southern Research Institute
2000 4th Ave
South Birmingham, Ala. 35205

Title of Research: Evaluations of Novel Particulate Control Devices

Sponsoring Agency or Source of Funding: EPA
: Dale L. Harmon

Cumulative Funding:
Start Date:

Projected Funding:
Completion Date:

Publications: EPA - 600/7-78-093

Control Technology/Process:

Aronetics scrubber uses waste heat to drive a two phase jet which produces a high energy spray that cleans and moves the gas.

Description of Research:

A pressurized, heated, liquid when passed through a properly designed nozzle will produce a two-phase mixture of vapor and liquid droplets that is an excellant cleaning medium. The most direct application is in the control of emissions from processes which generate high temperature gases, laden with submicron particles. An economizer type of heat exchanger is used to transfer thermal energy from the high temperature process exhaust gas to pressurized hot water which is delivered to the heat exchanger by a pump. Water exiting the heat exchanger is delivered directly to the nozzle in its liquid state (400°F, 350 psi). The gas and water are sprayed out the nozzle into a mixing section. The final component in the scrubbing system train is a separator which will remove the dirty water droplets and allow the clean gas to be discharged. Water drained from the separator is passed to water and treatment equipment and prepares the liquid for recycling. High efficiencies are achieved down to .1 um. A pressure rise develops of 30 to 40 inches of H_2O. Typical gas temperatures are around 1000°F and at 7000SCFM.

" The collection efficiency of the Aronetics Two Phase Scrubber determined by conventional total mass techniques on a source producing particulate having a mass mean diameter of about 3 um was 95.1 and 96.7%

Description of Research (cont'd):

for two days of testing. Measured fractional efficiencies were about 70% at 0.01um, about 35% at 0.05um, 35% at 0.1um, 99% at 0.5um, 99% at 1um, and 99.4% at 5um. The scrubber energy usage during the tests was approximately 633,000 JOULES/SCM (17000 BTU/1000SCF) at a net pressure rise of 12 1/2 to 16 in. H_2O. This energy usage was a result of using all the process waste heat available and may have been in excess of the minimum amnount required to achieve the efficiencies obtained during these tests. The energy used is from waste heat.

EFFLUENT RELEASE DATA

Effluent Nuclides	Particle Diameter	Removal Efficiency	Comment
	.2 to .5	90 to 99%	
	> .5	> 99%	
	< .1	40%	
	Overall	> 95%	

Assessment Parameters:

Effectiveness:

Cost: Not Addressed

Air Liquid Solid Residuals: Liquid waste residuals

Energy Consumption: Pump operation - usually offset by pressure rise developed by system.

Comments by PI:

Comments by Dames & Moore:

CONTROL TECHNOLOGY RESEARCH SURVEY

Principal Investigators: Joseph D. McCain

Location: Southern Research Institute
2000 4th Ave
South Birmingham, Ala. 35205

Title of Research: Evaluations of Novel Particulate Control Devices

Sponsoring Agency EPA
or : Dale L. Harmon
Source of Funding

Cumulative Funding:
Start Date: 6/74

Projected Funding:
Completion Date: 1/78

Publications: EPA - 600/7-78-093
June 1978

Control Technology/Process:

Venturi scrubber with variable throat

Description of Research:

Research consisted of testing efficiency of a variable throat venturi scrubber (Combustion Equipment Associates Inc.) on flue gas from Colstrip 360MW units. Device is basic scrubber but is equipped with a variable throat to maintain constant pressure drop at variable loads. Device is also used for SO_2 control with captured flyash providing alkalinity for the SO_2 removal.

Design parameters: Venturi: Pressure drop 17 in. H_2O
Residence time: 8 min.
Venturi L/G: 15 gal/1000ACF
Absorption Spray L/G: 18 gal/1000ACF
Total system pressure drop: 25.5 in.

Gas temperatures at inlet - 129°C to 137°C
Gas Flows: 280,000 DSCFM

EFFLUENT RELEASE DATA

Effluent Nuclides	Particle Diameter	Removal Efficiency	Comment
		> 99%	Overall effciciency
		94%	1 um
		60%	.5 um
		< 35%	.4
		80%	SO2 removal

(See next page)

Assessment Parameters:

Effectiveness:

Cost: Not Addressed

Air Liquid Solid Residuals: Slurry waste piped to settling pond

Energy Consumption:

Comments by PI:

Comments by Dames & Moore:

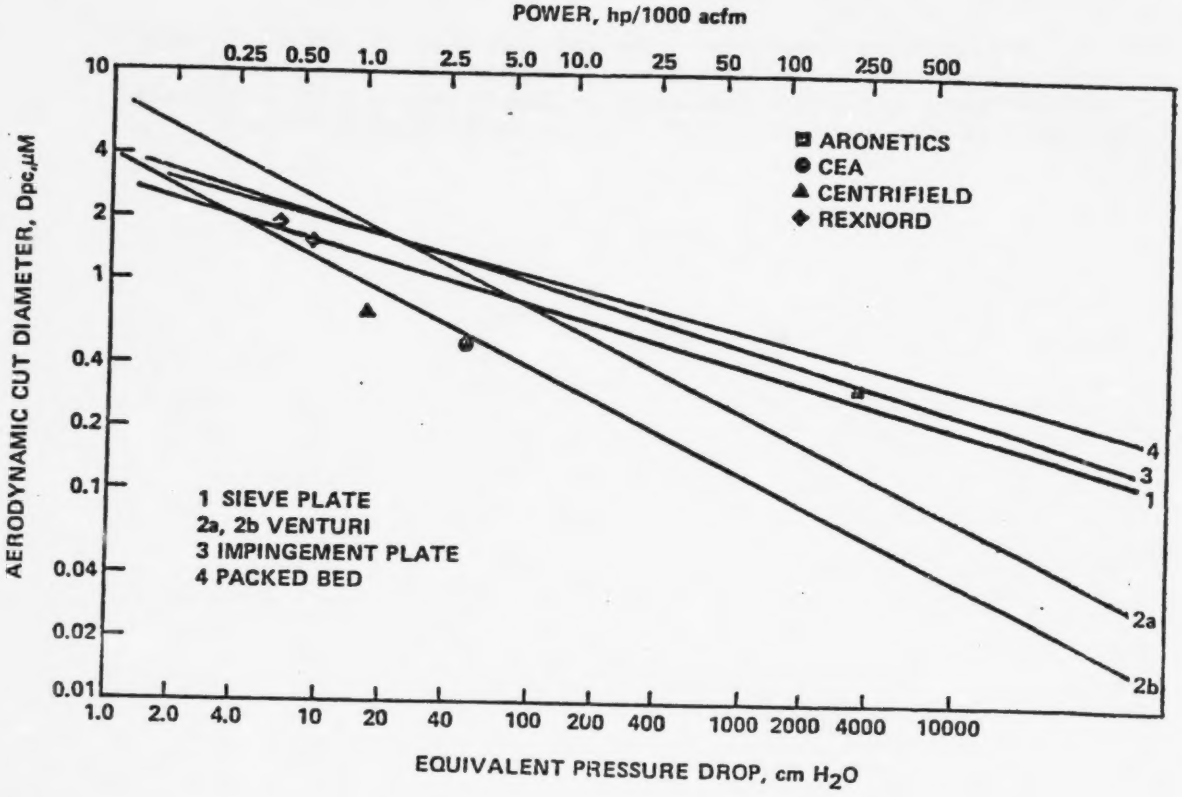
20% of particles < 5um
1% submicron

"The overall collection efficiency of the CEA variable throat scrubber, determined by conventional (Method 17) techniques on a pulverized coal fired power boiler producing particulate having a mass median diameter of about 20um ranged from 99.12 to 99.50 during three days of testing. The venturi pressure drop ranged from 44.5 cm w.c. to 48.3 cm w.c. Measured fractional efficiencies were about 5% at 0.06 um, 25% at 0.1um, 40% at 0.20um, 50% at 0.5 um, 98.4% at 1.0um, and 99.99% at 2um. The system energy usage during the tests was approximately 7200JOULES/DNCM (193BTU/1000/SCF). SO_2 collection efficiency ranged from 76.5% to 85.6%.

A comparison of the performance of the CEA scrubber with that of conventional scrubbers of various types is shown in Figure C.2.

"The results of this comparison indicate that the scrubber tested performed somewhat better than a well designed conventional venturi scrubber operating at the same pressure drop; however, the difference may well be within the uncertainty in the measured performance."

C



Representative cut diameters as a function of pressure drop for several scrubber types, after Calvert (1974), J. APCA 24:929.

FIGURE C.2

CONTROL TECHNOLOGY RESEARCH SURVEY

Principal Investigators: Douglas W. Cooper, Richard Wang, Daniel Anderson

Location: Number: GCA Corp.
Burlington Road
Bedford, MA. 01730

Title of Research: Evaluation of 8 Novel Fine Particle Collection Devices

Sponsoring Agency EPA
or : Dale Harmon
Source of Funding

Cumulative Funding:
Start Date:

Projected Funding:
Completion Date: 11/75

Publications: EPA - 600/2-76-035

C

Control Technology/Process:

Combines spray scrubbing and filtration.

Mystaire Scrubber

Description of Research:

MRI (Midwest Research Institute) and GCA did research. Air containing particulate and/or gaseous contaminants enters the scrubber passing through a spray and transversing a multi-layer wetted wire mesh screen, the Water Web. Gases are captured to an extent in the wetted screen by diffusion, and particulate material is caught by impaction, interception and diffusion. Captured material is drawn off by drains and removed from water, which may be recirculated.

Applications: Promotional literature claims it will caputure these pollutants: H_2S, SO_2, NO_2, Hydrofluoric acid, bacteria, ammonium chloride, titanium tetrachloride, formaldehyde, paint bake oven fumes, food processing odor and mineral oil fumes.

EFFLUENT RELEASE DATA

Effluent Nuclides	Particle Diameter	Removal Efficiency	Comment
	.5 - 1um	94%	MRI Study
	> 3um	99.9%	MRI Study
	< .1um	99.9%	MRI Study
	.5 - 1um	58.0%	GCA Study
	3umm	93%	GCA Study
	> 5um	100%	GCA Study
	.1um	88%	GCA Study
	.01um	100%	GCA Study

Assessment Parameters:

Effectiveness: Not Addressed

Cost:

Air Liquid Solid Residuals: Liquid waste water

Energy Consumption: 1.3 hp/1000 acfm (Less than conventional scrubbers)

Water Consumption: 60 gal/min/1000acfm (Greater that conventional scrubbers)

Comments by PI:

Comments by Dames & Moore: No information on flow rates or gas temperatures.

CONTROL TECHNOLOGY RESEARCH SURVEY

Principal Investigators: Manuel T. Rei and Douglas W. Cooper

Location: GCA Corp.
Burlington Road
Bedford, MA. 01730

Title of Research: Laboratory Evaluation of the Cleanable High Efficiency Air Filter (CHEAF)

Sponsoring Agency or Source of Funding: EPA - ORD
D. L. Harmon

Cumulative Funding:
Start Date:

Projected Funding:
Completion Date: 5/76

Publications: EPA - 600/2-76-202
July 1976

Control Technology/Process:

Combines features of filtration equipment, wet scrubbers and Brownian motion or diffusion controlled mist eliminators.

Description of Research:

Report gives results of testing CHEAF with many different variations of equipment. Particle collection occurs in the CHEAF at a reticulated wetted polyurethane foam filter which is placed over a rotating drum for support. The water acts as an aid in particulate collection at the foam and as a continuous cleansing agent. The drum is rotated in the CHEAF housing and is continuously wetted by spray nozzles mounted at locations around the drum housing. The sprays around the drum keep the pores of the foam lined with a film of liquid so that as particulate matter passes through the pores, they are placed in contact with the scrubbing solution and are either dissolved or agglomerated and captured in liquid drops. A Chevron-type mist eliminator is used to remove the bulk of the drops and a mesh-type mist eliminator is used to remove extremely small drops. The CHEAF is to be applied when high energy scrubbers or Brownian motion controlled mist eliminators are to be used (the study used iron-oxide aerosols). An overall mass efficiency was reported to be 95%. The size of the unit is much less than conventional scrubbers.

EFFLUENT RELEASE DATA

Effluent Nuclides	Particle Diameter	Removal Efficiency	Comment
	.5um	90%	Efficiencies are means of all
	1 - 3um	97%	test run variations
	5um	93%	
	7um	93%	
	9um	91%	

Assessment Parameters:

Effectiveness:

Cost:

Air Liquid Solid Residuals: Particulate matter is retained in liquid waste.

Energy Consumption: 8.3 hp/1000 acfm normal operating conditions and 1 hp for pumps and motors.

Water use: One gal/1000ft^3 of saturated gas this is 7-10 times less than Venturi scrubber)

Comments by PI:

Report indicates CHEAF is not commerically available.

Comments by Dames & Moore:

Incapable of handling > 5um size particles without pre-separating equipment. Many variables in use of equipment - spray rate, make up liquid rate, foam pores per inch, pressure drop, face velocity. Efficiencies are mean efficiencies for all variables tested, might be more or less depending upon different variables used. Operated at room temperature.

CONTROL TECHNOLOGY RESEARCH SURVEY

Principal Investigators: J. Schwab, D. Goodson, et al

Location: Air Pollution Systems Inc.
1114 Andover Park West
Seattle, Washington 98188

Title of Research: Development Program for an Ionizer-Precipitator Fine Particle Dust Collection System as Applied to Coal-Fired Utility System Generators.

Sponsoring Agency or Source of Funding: EPRI Research Project 386-1

Cumulative Funding:
Start Date:

Projected Funding:
Completion Date:

Publications: EPRI FP-291 October 1976 Final Report
Research Project 386-1

Control Technology/Process:

An ionizer is added as a charging stage to an ESP. The separation of the charging and collection stages allows reduced size of ESPs and higher charging efficiencies for fine particulates and for high gas velocities.

Description of Research:

Laboratory tests were conducted to determine optimum design parameters for pilot plant units. Phenomena studied in order to maximize design were back corona, anode surface resistivity, current flux and electric field at the anode, resistance to sparkover, and particle charging as a function of velocity. Field pilot testing at TVA (John Seiver Plant) indicated a reduction in penetration of 55% for high sulfur coal and 70% for low sulfur coal. Economic evaluations by Kaiser Engineers and Enviro Energy Corp. for the specific case of a 700MW coal burning facility handling 2 X 10^6 acfm of flue gas indicated potential savings of 30% per new installation and 20-70% for retrofit installations based on capital expenditures (cost data based on scale-up from lab results).

EFFLUENT RELEASE DATA   Not applied to radionuclides

Effluent Nuclides	Particle Diameter	Removal Efficiency	Comment

Assessment Parameters:

Effectiveness:

Cost: No data given on operating costs

Air Liquid Solid Residuals:

Energy Consumption: No data given on energy consumption

Comments by PI:

PI optimistic about results so far. Warrants further testing at actual installation.

Comments by Dames & Moore:

Field demonstration of this device underway at Arapaho Plant. Now with EPRI funding.

CONTROL TECHNOLOGY RESEARCH SURVEY

Principal Investigators: Schultz, M.A., Crotzen. M.E., and Knapisk, W.K.

Location: Penn State Nuclear Engineering Dept
University Park, PA 16802

Title of Research: Collection of Particulate Matter from Smokestacks Using Gamma Ray Inionization

Sponsoring Agency or Source of Funding: Schmidt Associates, Cleveland, Ohio and Environmental Systems, Youngstown, Ohio

Cumulative Funding:
Start Date:

Projected Funding:
Completion Date:

Publications: Nuclear Technology Vol. 17, January, 1973

Control Technology/Process:

Pre-conditioning of home type coal furnace emissions by charging with gamma rays. The charged particles are then collected in a conventional electrostatic precipitator (ESP)

Description of Research:

A small coal-burning stoke fed home-type furnace was installed adjacent to the cobalt pool of the Penn State Breazeale Nuclear Reactor Facility. The exhaust dust in which testing was conducted was 8 in. in diameter. Gas flow varied between 4 - 15 ft/sec. The Cobalt-60 gamma ray source was encapsulated in stainless steel double walled tubes 0.5 in. in diameter by 12 inches long which were arranged in a horseshoe pattern around the dust. The source rig was movable in a vertical and horizontal (radial) direction. A 50,000 V., 5 milli-amp power supply was used. In the charging unit, a high ion density is created throughout the pre-conditioning volume by photo-emission anddirect ionization. In a conventional ESP, charged particles are created near the center electrode and then drift to the outside walls and ionize the particles of the gas strem. It was theroized that the ion density of 10^7 ions/cm^3 in the gamma ray device created a space-charge phenomenon. Large numbers of both positive and negative charges were created by the 10,000 ci Cobalt-60 source.

Description of Research: (Cont'd)

For particles entering the charging field from the gas stream, field charging is thought to be the dominant charging mechanism for particles of >0.5um, while diffusion is more dominant for the smaller size fraction. For particles between 0.2um and 0.5um both mechanisms are active.

The Gamma ray precipitator (based on tests) exhibited a collection efficiency of 85% for 1um particles compared to 60% for the conventional ESP (based on full charging theory).

In addition to the collection efficiency advantage, the authors speculate that the following advantages and disadvantages would be present in the use of a gamma ray ESP:

ADVANTAGES

1. Cleaning without damage to the conventional ESPs fine central charging wire would be possible.
2. A more compact unit is possible.
3. The pilot scale unit required only 40 watts from incoming power lines. Conventional ESPs require several KW.
4. Conventional flow rates and velocities can be used.
5. Nuclear waste products can be used for charging.

DISADVANTAGES

1. Large amounts of radioactive material are required.
2. Shielding structures are required.
3. NRC licensing and additional paperwork would be required.

EFFLUENT RELEASE DATA

	Chemical Form	Removal Efficiency	Comment
Overall		90%	At 22-KV and 100 R/hr X 10-3
Overall		60 - 75%	At 22-KV and 1 R/hr X 10-3
Overall		96%	At 27-KV and no dose

Assessment Parameters:

Effectiveness:

Cost: Not addressed

Air Liquid Solid Residuals:

Energy Consumption: 40KW for pilot scale charging unit. Not much more for full sized unit compared to several KW for conventional ESP corona charging wire.

Comments by PI:

Warrants further study in the following areas: Theroetical understanding and effect of resistivity of particles, flow rate, temperature, and gamma source configurations.

Comments by Dames & Moore:

Overall cost study also required. Cost for source handling, shielding, and paperwork could outweigh advantages.

CHAPTER V

Introduction

The use of radiopharmaceuticals in diagnostic and therapeutic medicine has steadily increased in the last decade and is expected to continue. In 1976, for example, it was estimated that there were approximately three thousand departments of nuclear medicine in the United States.(1-1) This number increased to well over four thousand in 1978, and is currently increasing at a rate of 15% per year.(1-2)

The rapid growth of these facilities has caused some concern because of the potential for radioactive releases to the environment. This chapter presents a brief overview of the use of radiopharmaceuticals, and a review of the control technologies currently used or projected which may be employed to reduce their atmospheric emission.

Uses of Radiopharmaceuticals

The uses of radiopharmaceuticals in medical practice may be grouped into three major classess: diagnostic, therapeutic and research.(1-3) Of these, the diagnostic class may be further subdivided into a function category and a scanning category. The function category consists of procedures used to determine a particular metabolic parameter of a selected organ. Examples include studies of thyroid uptake, cardiac and pulmonary circulation times, and kidney functions (renography). The scanning category includes procedures which enable technicians to determine the distribution of a radionuclide throughout a selected organ. The organ is scanned using an array of scintillation detectors or equivalent instrumentation and an image is formed. The image may accentuate areas useful to the physician in the diagnosis of an illness. Common examples of this category include lung scans, thyroid scans and placental localization. The activities of the radioisotopes used in diagnostic procedures are generally of the order of uCi to a few mCi.

Currently, therapeutic uses of radiopharmaceuticals form a much smaller category of procedures. These procedures are principally for the treatment of disease. The radioisotopes involved usually have a greater activity than those employed in diagnosis. Examples of such procedures include treatment of hyperthyroidism, selected carcinomas, cardiac dysfunction and polycythemia vera.

It should be noted that while the inventory of radionuclides in a typical hospital may be in the curie range, the amount used in either of the above procedures is generally of the order of uCi to mCi.(1-3) Tables 1-1.a and b present the major diagnostic and therapeutic procedures in use. A more complete list may be found in Appendix V.A.(1-4, 1-5)

While information exists on diagnostic and therapeutic radiopharamaceuticals, very little was found on those in the research category. The major reason for this lack of information is protection for the manufacturer. Currently, the Food and Drug Administration classifies pharmaceuticals, including radiopharmaceuticals, by either an investigational drug number (IDN), or new drug approval number (NDA). The investigational drugs, classified as being in the research stage, are considered proprietary, and therefore exempt from requests for information under the Freedom of Information Act. The NDA numbers are listed in Appendix V.A, and are those currently used for diagnosis or therapy.

Isotopes of Concern

The isotopes of concern for this report are those which may be vented as particulates or gases into the atmosphere. A review of the NDA list shows that the possible airborne effluents include xenon gas, volatilized iodine and gaseous fluorine. Table 1-2 lists the isotopes of concern, their half-lives and major radiations. It should be noted that fluorine will be eliminated from further

TABLE 1-1a

Frequently Performed Radiopharmaceutical Diagnostic Examinations

Type of Examination	Radionuclides	Chemical Form	Average Administered Activity (uCi)	Examined and/or Critical Organ
Thyroid scan or function	I-131	Iodide	25	Thyroid
Thyroid scan	Tc-99m	Pertechnetate	1000	Thyroid
Thyroid function	I-132	Iodide	25	Thyroid
Kidney function	I-131	o-Iodohippurate	20	Kidney
Bone scan	Sr-85	Nitrate/chloride	100	Skeleton
	Sr-87m	Nitrate/chloride	1000	Skeleton
	Tc-99m	Polyphosphate	10000	Skeleton
Kidney scan	Hg-283	BMHP	100	Kidney
	Hg-203	Chlormerodrine	150	Kidney
	Tc-99m	DTPA	3000	Kidney
Brain scan	Tc-99m	Pertechnetate	10000	Thryoid
Spleen scan	Hg-197	BMHP	300	Spleen
	Tc-99m	S-colloid	1500	Spleen
Liver scan	Au-198	Colloid	150	Liver
	Tc-99m	S-colloid	1500	Liver
	In-133m	Colloid	1000	Liver
Pancreas scan	Se-175	Methionine	200	Pancreas
Blood (plasma) volume	I-131	HSA	10	Total body
	Tc-99m	HSA	100	Total body
Erythrocyte volume or survival time	Cr-51	Chromate	100	Total body

TABLE 1-1b

Frequently Performed Radiopharmaceutical Therapy Procedures

Type of Procedure	Radionuclides	Average Administered Activity (mCi)	Organ
Hyperthyroidism	I-131	5	Thyroid
Thyroid Carcinoma	I-131	50-150	Thyroid
Thyroid Abalation	I-131	80	Thyroid
Malignant Effusions	Au-198	100	Whole body
Polycthemia Vera	P-32	4-8	Bone marrow

TABLE 1-2

Isotopes of Principal Concern

Isotope	Half Life	Radiation Maximum Energies (MeV)	Radiation Main Energies (MeV)	
Fluorine-18	110 m	0.633 (97%)	0.51[a]	
Iodine-123	13 h	100% EC	0.16 (84%)	
Iodine-125	60 d	100% EC	0.035 (7%)	
Iodine-131	8.04 d	0.61 (87.2%)	0.28 (5%)	0.36 (79%)
		0.81 (0.7%)	0.64 (9.3%)	0.72 (2.8%)
Xenon-133	5.3 d	0.34 (99%)	0.34 (99%)	0.81 (35.5%)
		0.27 (1%)	0.27 (1%)	0.16 (0.5%)

---

a. Electron-Positron Annilation resulting in two 0.511 MeV gammas.

discussion because the sole manufacturer of the radiopharmaceuticals containing fluorine (^{18}F) has ceased production. Also of some concern is the possible release of the technetium isomer (^{99m}Tc) from the incineration of sludge. This question is currently being reviewed under a separate contractor for the U.S. Environmental Protection Agency.

From Table 1-2 it can be seen that the two major elements of concern are iodine and xenon. The following discussion will review the possible sources of emissions of these isotopes, and the control technologies which can be used to limit their airborne emission. Also, as the control techniques are chemically based, no further distinction between the individual isotopes of iodine or the individual isotopes of xenon will be considered.

Radioiodine

Sources of Airborne Radioiodine

Radioiodine may escape into the air at several points during utilization. Sources of airborne radioiodine emissions are dependent on the physical form of administration, which in turn is dependent on the proceedure dictated by the physician. Under normal conditions radioiodine is administered via injection, capsules or as an oral solution. Of these three methods, oral solutions represent the major vehicle for release. This is due to the chemical volatility of iodine, and especially due to the ease with which the bound radioiodine can be oxidized to elemental iodine. "Therapeutic iodine solutions consist of sodium iodide (NaI). The iodide ion is the anion of a strong acid and is fully ionized in water. It can be oxidized to iodine by atmospheric oxygen in acid solution. The reaction is catalyzed by light; iodide solutions are therefore usually kept in dark bottles. Atmospheric carbon dioxide dissolves in water to form a mildly acidic solution, creating the condition for air oxidation. The glass of therapeutic iodine bottles is coated to prevent a reaction of the iodide with the glass and to prevent shattering."(1-5)

The urine or perspiration from a patient containing radioiodine in an unbound state is also a possible source of airborne emissions. For example, half of the administered dose may be excreted in the urine within the first two days.(1-6) No known nuclear medicine department controls perspiration release. It is considered to be patient excreta. Radiation protection criteria seem to exempt perspiration from controls. Some hospitals, however, have studies planned to determine the source term from patient perspiration in order to determine if controls should be instituted.(1-6)

A last possible source is the "empty" vials of radioiodinated solutions. Unused iodine, typically less than 10 ml, is disposed of in its vial as solid waste. Proper disposal of all vials to a shallow land burial site should negate this source.

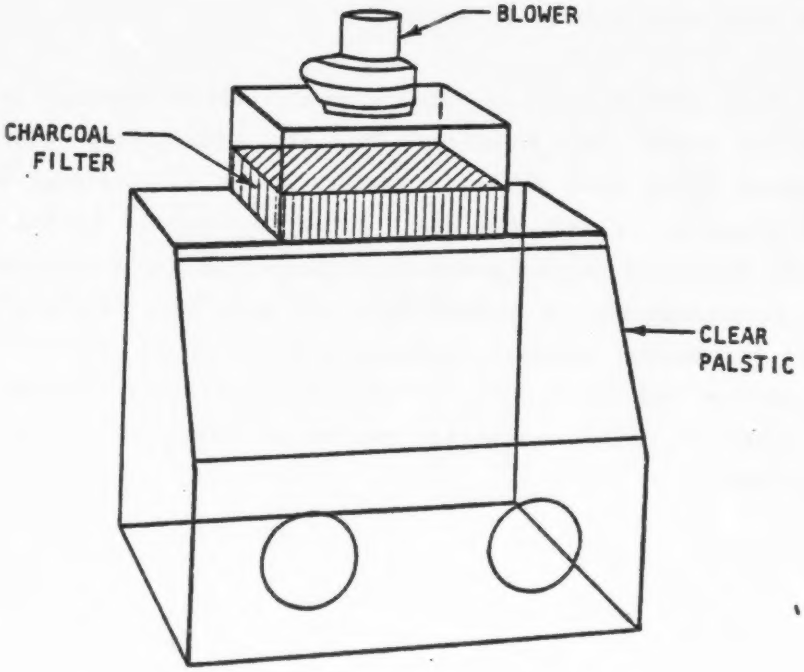
Radioiodine Control

Two types of "controls" may be used to regulate emission of airborne radioactive iodine. The first, a direct control, employs an activated charcoal filter in an iodination box in conjunction with a fume hood. The second form of control is indirect, and is dependent on the form of administration of radioiodine.

The iodination box, currently used at the Walter Reed Army Medical Center for all procedures involving the use of 1 mCi or more of radioiodine, (1-8) is typical of an exemplary control. Figure 1.1 shows the chamber. "Basically it is constructed of 1/4 in. clear plastic, has two 5 in. diameter portholes and a front opening door for easy access during experimental work. The unit employs replaceable activated charcoal filters measuring 12 X 12 X 2 in., and a 100 CFM blower which provides approx. 200 FPM through the portholes. Such boxes have been used successfully inside existing fume hoods and on bench tops with a flexible hose exhausting the box into the exhaust stream of the fume hood. With the filter filled with activated (Cambridge Carbon) charcoal, initial collection efficiencies between 90 and 100% have been measured."(1-9) The cost of the iodination box is estimated at approximately $700 in 1978.

The second form of control is an alternative mode of radioiodine administration. For example, if the iodine was administered by injection rather than orally, all solutions would be closed to the atmosphere, and all preparations would involve syringes and rubber septums. This would eliminate all modes of atmospheric release except via patient perspiration.

There are, however, disadvantages to this method. First, the


BLOWER
CHARCOAL FILTER
CLEAR PALSTIC

IODINATION BOX

FROM REF. 1-10

FIGURE 1.1

solution would have to be pyrogen (fever producing) free in order to be injected directly into the blood stream. This would increase its cost. Second, and more importantly, intravenous administration would involve the introduction of the medically unnecessary, albeit small, risk associated with an injection.

Oral administration can be accomplished through the use of capsules rather than solution. This also effectively eliminates all releases other than patient's excreta. The disadvantage associated with capsules is that the dose cannot be adjusted in the hospital. Liquid solutions may be given to a patient in any amount dictated by the circumstances. A capsule does not have that flexibility. However, for nuclear medicine departments that can anticipate their needs in advance and which only occasionally administer iodine, the use of capsules is the exemplary method of handling iodine airborne emissions.

Radioxenon

Sources of Airborne Xenon-133

Like radioiodine, possible emission sources of xenon-133 are dependent on the physical forms of administration. There are two sources, the first of which is injection of xenon dissolved in a saline solution. This procedure is used for studies of cardiac abnormalities, cerebral blood flow, pulmonary function and muscle blood flow. The emission source of airborne xenon from this procedure is the patient. Approximately 95% is discharged from the body through the alveoli with the first passage of activated blood through the lung.(1-11) When injected into the carotid artery, the gas is retained briefly by the brain and subsequently discharged back to the blood. "When injected into muscle tissue, the gas is transported by capillaries to the venous circulation.(1-3)" It should also be noted that xenon in saline will remain in solution only in containers completely filled with liquid. The containers must be kept free of air.

The second method of xenon administration is by inhalation. This procedure is primarily for lung scanning, but may be used in the evaluation of pulmonary functions, or the assessment of cerebral blood flow. A variety of devices are available for the procedure ranging from a simple hand-held dispenser with breathing bag to a completely closed system with spirometer, bacteriological filters and xenon trap. (1-12, 1-13, 1-14) The latter method has the capability of capturing and possibly reusing the xenon.(1-15)

The major emission source of radioactive xenon from the inhalation delivery system is leakage, especially around the patient's mouthpiece.(1-15) Respirators, spirometers and their associated tubing assemblies must be as leak-proof as possible to prevent loss of xenon to the surrounding environs.

Radioxenon Control

There are three major methods of disposal of radioxenon after the completion of a procedure. In the first, the patient exhales into a standard laboratory fume hood to the atmosphere. The second method involves having the patient exhale into a plastic bag (Douglas bag) which is usually emptied into a standard laboratory fume hood. The last is the use of an activated charcoal xenon trap. The basic function of the trap is to allow the expunged xenon to be adsorbed onto the activated charcoal. Once adsorbed, the xenon eventually decays to stable, non-gaseous cesium.

The adsorption of xenon depends on a variety of parameters. Most traps in the U.S. use a type G210 activated charcoal available from North American Carbon, Columbus Ohio.(1-17)

The following discussion by Gerald M. Timpe (Radx Corp) in a Journal of Nuclear Medicine Technology reviews some of the problems inherent in the use of these traps.(1-17)

> "It should be noted that the activated charcoal used in most units has... specific adsorption characteristics. These characteristics are dependent on (A) the amount of charcoal in the trap and (B) in the method used to pack the cartridge. Item B is particularly important with horizontal units where care must be taken to prevent top channeling through settling.
>
> The K_D (dynamic absorption coefficient) for G210 is 725 cm^3/gm at 25°C, $7.6x10^{-3}$ mm Hg (10 ppm), and a velocity of 2.0 ft/min. This translates into an absorption capacity of $7.24x10^5$ cm^3 of xenon. The theoretical capacity of ^{133}X is $2.0x10^5$ Ci/gm, which converts to $1.8x10^3$ Ci/cm^3 at STP. Therefore a trap using G210 will have an absorption capacity of $8.56x10^8$ Ci Xe-133 per kg of charcoal, ignoring decay! However, it is important to note that this activated charcoal will not only absorb

radioactive xenon, but also a tremendous amount of airborne contaminants. In its simplest form, it can be used to remove odors from refrigerators and smoke from rooms. It has no capacity to selectively absorb xenon in the presence of contaminants and therefore will reach its total absorption capacity long before it reaches the calculated xenon-133 absorption capacity. Moisture will deactivate the charcoal very rapidly; therefore, an efficient desiccant system is absolutely necessary.

A second observation apparently relates to the total amount of air, in a time relationship, which passes through the trap. It has been determined previously by other developers in the area, and we concur, that best absorption takes place below a flow rate of 5 to 10 l/min. This is, of course, geometry dependent and relates to xenon dwell time in the charcoal. However, an additional factor affects the trapping, and that is the total amount of air which passes through the system in a given period of time.

At one installation our xenon trap was inadvertently left running continuously over a 48-72 h period. The built-in saturation detector alarm activated, indicating xenon-133 in the exhaust port. Since the unit was new, we concluded that an electrical malfunction had occurred and proceeded to replace the alarm system. The second alarm system activated immediately. A scintillation camera image of the cartridge pack indicated xenon-133 distributed throughout the six cylinders uniformly across the circumference but continuously declining along the longitudinal flow path from intake to exhaust. The trap was leaking as indicated by the detector alarm system. This phenomenon is easy to understand if we consider the process a chromatographic one with charcoal as the suspension media and air as the solvent.

Another problem was detected in our development work which we have not seen discussed in the literature. People normally breathe at a rate of 15 l/min and charcoal traps are most efficient at 5-10 l/min. The pressure buildup against a patient breathing faster than the trap air movement can approach 5 cm of water, which is considerable even for a healthy person. The situation is readily eliminated by use of an expandable interface which allows the excess exhaled air to expand a bag and later be pumped from the bag after the patient has been removed. An alternative is to collect the washout in a bag and later attach it to the intake port of the xenon trap. If an expandable interface is used, it must have sufficient capacity to store the excess until washout is completed. In our experience a minimum capacity of 50l is required."...

Discussion

"From our development work we have concluded and recommended the following:

1. All xenon traps will saturate, which will subsequently result in dumping of xenon-133 into the nuclear medicine department where the procedures are performed. The overall situation is probably a very complex function of many variables such as air flow rate through the charcoal, geometry of the charcoal filter system, total air volume through the filter, humidity, temperature, air pollution, amount of charcoal, type of charcoal, concentration of xenon-133 in the air, and perhaps even what the patient had to eat the night before.

2. The desiccant should be checked frequently and changed or reconstituted when early signs of saturation appear.

3. Maximum flow rate through a charcoal trap should not exceed 10 l/min and preferably be around 5 l/min.

4. Xenon traps should run only when necessary.

5. Expandable interfaces should be used between the patient and trap to facilitate patient breathing.

6. Charcoal cartridges may or may not be reused after decay depending on what caused the leak in the first place. Saturation with moisture or air pollutants would seem to negate reuse after decay, whereas leakage caused by excessive air movement could be eliminated by decay, thus allowing reuse.

7. The exhaust port of xenon traps should be monitored continuously or at least daily for xenon-133.

Perhaps our experiences with the xenon trap system will lead others to more thoroughly investigate the dynamics of the system.

Last, although cooling the charcoal trap would increase its capacity, this practice (although common in research) is not in common practice."

Control Costs

The costs of the control technologies currently available are presented in Tables 1-3 and 1-4. As seen, these costs are somewhat dependent on the mode of radionuclide administration to the patient. Also, the types of controls chosen may vary depending on the number of yearly procedures of a specific type. For example, a small hospital with a limited number of radioiodine procedures per year may decide to use non-volatile capsules rather than radioiodide liquid. For nuclear medicine departments with relatively large workloads the use of activated charcoal filters in conjunction with fume hoods or a commercial iodination box would be preferrable. Most of the controls listed in the tables use activated charcoal. Table 1-5 presents the costs of the charcoal from simple bulk charcoal to a caisson using stainless steel.

TABLE 1-3

Radioiodine Control Technology Costs

System	Cost($)
Fiberglass Radioisotope[a] Glove Box Without Charcoal	1,900
Stainless Steel Hood[a] Without Blower or Activated Charcoal	2,500-3,500
Hood Blowers[a]	500-2,700
Diagnostic (<100 uCi)[b] Sodium Iodine Capsules	1.40 each
Therapeutic Sodium[b] Iodine Solution	5 mCi - $15 10 mCi - 20 20 mCi - 30 50 mCi - 60

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[a] Fisher Scientific Co. (1977).
[b] Various manufacturers.

TABLE 1-4

Radioxenon Delivery/Control Technology Costs

Company	System	Cost (1978)
RADX[a]	Xenon gas delivery system with built-in xenon trap, expandable interface, and xenon trap exhaust port monitor detector alarm	$4,000
RADX	Xenon trap with detector warning system	4,000
ADC[b]	Xenon gas delivery system with xenon charcoal, gas traps	2,000
Nuclear Associates[c] (Victoreen)	Xenon trap with detector warning system	1,100 1,750 2,850
Nuclear Associates (Victoreen)	Xenon gas delivery system with xenon trap	1,800 950 2,750

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[a] RADX Corporation, Houston, Texas (1979).

[b] ADC Medical, Farmingdale, NY (1978).

[c] Nuclear Associates, Carle Place, NY (1979).

TABLE 1-5

Activated Charcoal and Ancillary Equipment Costs

System	Material	Cost($ 1979)[a]
Activated Charcoal	(Bulk)	1.85 - 3.60 per pound
Activated Charcoal	2 inch tray with impregnation	420 - 560
Activated Charcoal	1 inch bed in carbon steel caisson	660 - 750
Activated Charcoal	1 inch bed in stainless steel caisson pleated cell 14 1/2 inch deep	935 - 1,025
Activated Charcoal	2 inch bed with carbon steel pleated cell 14 1/2 inch deep	1,105 - 1,240
Activated Charcoal	2 inch bed with stainless steel	1,315 - 1,495
--	Caisson with carbon steel	1,100/1,000 cfm
--	Caisson with stainless steel	1,800/1,000 cfm

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[a] Confidential quote.

Summary

Emissions from isotopes of iodine may be controlled by either of two processes. For nuclear medicine departments with relatively large workloads, and using sodium iodide solution for its flexibility, the use of activated charcoal filters in conjunction with fume hoods provides maximum effectiveness. Smaller nuclear medicine departments can best control the release of radioiodine to the atmosphere by the use of non-volatile capsules rather than liquid containing the iodine.

The control for limiting xenon effluents from both the inhalation and injection mode of administration is the use of activated charcoal traps.

It appears likely that projected improvements in airborne controls will arise from refinements of existing technologies rather than from novel approaches. Isotopes projected as having increased use in the future will typically have extremely short half lives and no controls will be utilized over their release.

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APPENDIX VA

Abbreviated Summary of Approved Radiopharmaceutical Drug Products

APPENDIX V-A

ABBREVIATED SUMMARY OF APPROVED RADIOPHARMACEUTICAL DRUG PRODUCTS

NDA	Trade Name	Date Orig. Approved	Firm	Indication
Technetium Tc 99m Aggregated Albumin Kit				
17-833	"Macrotec"	5/3/74	Squibb	Pulmonary embolus, pulmonary cirulation, neoplasm, tuberculosis and emphysema. Used in radionuclide venography as an adjunct in the screening, diagnosis, and management of of deep vein thrombosis in the lower extremities.
17-842	"Tevhne Scan MAA"	6/7/74	Mallinckrodt	Pulmonary embolus, chronic obstructive pulmonary disease, certain pathological conditions, e.g., carcinoma and pulmonary abscess.
17-833	"Lungaggregate Reagent"	8/20/74	Medi-Physics	Regional plumonary perfusion, regional pulmonary ischemia pulmonary embolus, neoplasm and obstructive lung disease.
17-773	"MAA Kit"	11/16/76	Union Carbide	Lung imaging as an adjunct in the evaluation of pulmonary perfusion.
17-776	"Pulmolite"	11/16/76	New England Nuclear	Lung imaging as an adjunct in the evaluation of pulmonary perfusion.
17-792	Aggregated Albumin (Human) Kit	1/19/77	CIS	Lung imaging as an adjunct in the evaluation of pulmonary perfusion.
17-916	"A-N Stannous Aggregated Albumin	3/20/78	A-N Radiopharmaceuticals	Lung imaging as an adjunct in the evaluation of pulmonary perfusion.

APPENDIX V-A (cont'd)

ABBREVIATED SUMMARY OF APPROVED RADIOPHARMACEUTICAL DRUG PRODUCTS

NDA	Trade Name	Date Orig. Approved	Firm	Indication
Technetium Tc 99m Aggregated Albumin				
17-848	Technetated Albumin (Human) Lung-aggregate	2/3/76	Medi-Physics	Regional pulmonary perfusion, regional pulmonary ischemia pulmonary embolus, neoplasm and obstructive lung disease.
Technetium Tc 99m Albumin Microspheres Kit				
17-832	Albumin Microspheres (Human) 'Instant Microspheres'	1/31/72	Nuclear Products Div. of 3 M	Pulmonary embolism, chronic obstructure, pulmonary disease, pulmonary abscess, pulmonary pneumonia and tuberculosis. Used in radionuclide venography as an adjunct to other diagnostic procedures where deep venous thrombosis in the lower extremities is suspected.
Technetium Tc 99m Serum Albumin Kit				
17-775	Technetium 99m HSA Kit	4/1/77	Union Carbide	Used for imaging the heart blood pool and to assist in the detecion of pericardial effusion and ventricular aneurysm.
17-775 S-002	Technetium 99m HSA Kit	4/1/77	Distribution by Searle	Used for imaging the heart blood pool and to assist in the detecion of pericardial effusion and ventricular aneurysm.
Chlormerodrin Hg 197 Injection				
17-269	Chlormerodrin Hg 197 Inj.	6/3/74	Mallinckrodt	Kidney and brain imaging.
16-642	Chlormerodrin Hg 197 Inj.	3/7/72	Squibb	Kidney and brain imaging.

APPENDIX V-A (cont'd)

ABBREVIATED SUMMARY OF APPROVED RADIOPHARMACEUTICAL DRUG PRODUCTS

NDA	Trade Name	Date Orig. Approved	Firm	Indication
		Chlormerodrin Hg 203 Injection		
16-646	Chlormerodrin Hg 203 Inj.	4/24/73	Mallinckrodt	Brain imaging.
		Chromic Phosphate P 32 Colloidal Suspension		
17-259	Chromic Phosphate P 32 Sterile Suspension	10/30/74	Abbott	Suppression of pleural and peritoneal effusions of malignant origin; palliative or destructive treatment of prostatic and bladder tumors.
17-084	"Phosphocol P 32"	9/23/74	Mallinckrodt	Treatment of peritoneal or plueural effusions cuased by metastatic disease; interstitital treatment of cancer.
		Cyanocobalamin Co 57		
14-084	"Racobalamin-57" Kit	8/23/63	Abbott	Diagnosis of Addisonian (pernicious) anemia, diagnostic adjunct in other defects of intestinal absorption.
14-085	"Racobalamin-57" Caps	8/23/63	Abbott	Diagnosis of Addisonian (pernicious) anemia, diagnostic adjunct in other defects of intestinal absorption.
14-086	"Racobalamin-57" Inj.	8/23/63	Abbott	Diagnosis of Addisonian (pernicious) anemia, diagnostic adjunct in other defects of intestinal absorption.
16-635	Cyanocobalamin Co 57 Caps	6/21/68	Mallinckrodt	Diagnosis of Addisonian (pernicious) anemia, diagnostic adjunct in other defects of intestinal absorption.
16-089	"Rubratope-57" Caps	12/21/70	Squibb	Diagnosis of Addisonian (pernicious) anemia, diagnostic adjunct in other defects of intestinal absorption.

APPENDIX V-A (cont'd)

ABBREVIATED SUMMARY OF APPROVED RADIOPHARMACEUTICAL DRUG PRODUCTS

NDA	Trade Name	Date Orig. Approved	Firm	Indication
		Cyanocobalamin Co 57 & Co 58		
17-406	"Dicopac" Kit Kit	6/10/74	Amersham	Diagnosis of Addisonian (pernicious) anemia, diagnostic adjunct in other defects of intestinal absorption.
		Cyanocobalamin Co 60		
11-510	"Racobalamin" Co 60	6/10/59	Abbott	Diagnosis of Addisonian (pernicious) anemia, diagnostic adjunct in other defects of intestinal absorption.
16-634	Cyanocobalamin Co 60 Caps	6/21/68	Mallinckrodt	Diagnosis of Addisonian (pernicious) anemia, diagnostic adjunct in other defects of intestinal absorption.
16-090	"Rubratope 60" Caps	12/18/70	Squibb	Diagnosis of Addisonian (pernicious) anemia, diagnostic adjunct in other defects of intestinal absorption.
		Ferrous Citrate Fe 59 Injection		
16-729	Ferrous Citrate Fe 59 Inj.	12/17/73	Mallinckrodt	Iron turnover studies, which include clearance of iron from plasma, appearance of iron in newly synthesized red blood cells and in various body sites; absorption of iron from the intestine (oral administration).
		Fluorine F 18 Injection		
17-042	Fluorine 18 Inj.	2/24/72	Medi-Physics	Bone imaging agent to define areas of altered osteogenic activity.

APPENDIX V-A (cont'd)

ABBREVIATED SUMMARY OF APPROVED RADIOPHARMACEUTICAL DRUG PRODUCTS

NDA	Trade Name	Date Orig. Approved	Firm	Indication
		Gallium Citrate Ga 67		
17-478	Gallium Citrate Ga 67	5/17/76	New England Nuclear	May be useful to demonstrate the presence and extent of the following malignancies: Hodgken's disease, lymphomas and bronchogenic carcinoma.
17-700	Gallium Citrate Ga 67	12/16/77	Diagnostic Isotopes	May be useful to demonstrate the presence and extent of Hodgkin's disease or lymphoma.
17-655	"Neoscan"	5/1/78	Medi-Physics	May be useful to demonstrate the presence and extent of Hodgkin's disease, lymphomas, and bronchogenic carcinoma.
		Gold Au 198 Injection		
9-510	"Aurcoloid-198" (Therapeutic)	10/1/54 (Discontinued 7/1/74)	Abbott	Palliative management of ascites and pleural effusion associated with metastatic malignancies in closed serous cavities.
10-928	"Aureotope" (diag. and therap.)	4/2/57	Squibb	Therapeutic: palliative management of ascites and pleural effusion associated with metastatic malignancies; Diagnostic: liver imaging.
		Oleic Acid I 125		
17-231	Oleic Acid I 125 Capsules	9/24/73	Mallinckrodt	Estimate fatty acid absorption.

APPENDIX V-A (cont'd)

ABBREVIATED SUMMARY OF APPROVED RADIOPHARMACEUTICAL DRUG PRODUCTS

NDA	Trade Name	Date Orig. Approved	Firm	Indication
		Potassium Perchlorate		
17-551	"Perchloracap"	11/21/74	Mallinckrodt	To minimize the accumulation of pertechnetate Tc 99m in the choroid plexus, the salivary and thryoid glands.
		Chromium Cr 51 Serum Albumin		
17-835	"Chromalbin"	3/18/66	Squibb	Gastrointestinal protein loss, hypoproteinemia and placenta localization.
		Iodinated I 125 Fibrinogen		
17-787	Radionuclide Labeled (125 I) Fibrinogen (Human) Sensor	6/28/76	Abbott	For use as an aid in the diagnosis of deep-vein thrombosis of the legs.
17-879	Ibrin	12/21/77	Amersham Corporation	For use as an aid in the diagnosis of deep-vein thrombosis of the legs.
		Iodinated I 125 Serum Albumin		
17-840	RISA-125-H	7/28/64	Abbott	Blood and plasma volume determination. Metabolism and turnover studies.
17-836	"Albumotope 125 I"	11/13/63	Squibb	Blood and plasma volume determination. Metabolism and turnover studies.
17-844	Radioiodinated Serum Albumin (Human) (IHSA I-125)	5/6/66	Mallinckrodt	Blood and plasma volume determinations. Blood circulation studies.

APPENDIX V-A (cont'd)

ABBREVIATED SUMMARY OF APPROVED RADIOPHARMACEUTICAL DRUG PRODUCTS

NDA	Trade Name	Date Orig. Approved	Firm	Indication
		Iodinated I 125 Serum Albumin (cont'd)		
17-846	Radioiodinated I 125 Serum Albumin (Human)	8/6/68	Miles	Blood and plasma volume determinations.
17-839	"Macroscan-131"	6/23/67	Abbott	Pulmonary emboli, bronchogenic carcinoma, penumonitis, pulmonary emphysema, chronic pulmonary tuberculosis and pulmonary disorders.
17-834	"Albumotope L-S"	10/15/65	Squibb	Pulmonary emboli, pulmonary vascular obliteration, cogenital heart disease, diffusion pulmonary disorders.
17-843	Aggregated Radioiodinated (I 131) Albumin (Human) (MAA I 131)	9/20/67	Mallinckrodt	Pulmonary embolism, infarctions and embolus.
		Iodinated I 131 Serum Albumin (Human)		
17-841	RISA-131-H	5/20/54	Abbott	Blood and plasma volume determinations, brain tumor localization, blood flow studies.
17-837	"Albumotope 131 I"	12/20/57	Squibb	Blood and plasma volume, cardiac output, cardiac and pulmonary blood volumes, circulation times, protein turnover, placenta localization, brain and heart imaging.
17-845	Radioiodinated Serum Albumin (Human) (IHSA I-131)	7/7/64	Mallinckrodt	Blood and plasma volumes, brain tumor localization metastatic of the liver, blood circulation and cardiac output, placenta localization.

APPENDIX V-A (cont'd)

ABBREVIATED SUMMARY OF APPROVED RADIOPHARMACEUTICAL DRUG PRODUCTS

NDA	Trade Name	Date Orig. Approved	Firm	Indication
17-847	Radioiodinated (I 131) Serum Albumin	5/6/66	Miles	Blood and plasma volume determinations.
		Selenomethionine Se 75 Injection		
17-047	"Sethotope"	5/7/73	Squibb	Pancreatic imaging as an aid in the diagnosis of suspected pancreatic disease.
17-098	Selenomethionine Se 75	5/7/73	Mallinckrodt	Pancreatic imaging as an aid in the diagnosis of suspected pancreatic disease.
17-564	Selenomethionine Se 75	6/3/75	Amersham/ Searle	Pancreatic imaging as an aid in the diagnosis of suspected pancreatic disease.
17-257	Selenomethionine Se 75	11/9/76	Diagnostic Isotopes	Pancreatic imaging as an aid in the diagnosis of suspected pancreatic disease.
17-322	Selenomethionine Se 75	8/11/77	CIS	Pancreatic imaging as an aid in the diagnosis of suspected pancreatic disease.
		Sodium Chromate Cr 51 Injection		
9-919	"Rachromate-51"	9/20/55	Abbott	Determination of red blood cell volume or mass, study of red blood cell survival time, evaluation of blood loss.
13-993	"Chromitope Sodium"	12/27/71	Squibb	Determination of red blood cell volume or mass, study of red blood cell survival time, evaluation of blood loss.
16-708	Sodium Chromate Cr 51 Inj.	12/23/71	Mallinckrodt	Determination of red blood cell volume or mass, study of red blood cell survival time, evaluation of blood loss.

APPENDIX V-A (cont'd)

ABBREVIATED SUMMARY OF APPROVED RADIOPHARMACEUTICAL DRUG PRODUCTS

NDA	Trade Name	Date Orig. Approved	Firm	Indication
		Sodium Iodide I 123		
17-630	MPI Iodine 123	3/24/76	Medi-Physics	Diagnosis of thryoid function and imaging.
		Sodium Iodide I 125		
17-222	Nat I 125	7/18/73	Mallinckrodt	Diagnosis of thyroid function. To localize metastases associated with thyroid malignancies.
17-278	Nat I 125 Solution	7/20/73	Mallinckrodt	Diagnosis of thyroid function. To localize metastases associated with thyroid malignancies.
		Sodium Iodide I 131		
8-200	Sodium Iodide I 131 Oral Solution and Caps	11/23/51	Abbott	Diagnosis of thyroid function, for thyroid imaging. To localize metastases associated with thyroid malignancies. Treatment of hyperthyroidism and selected cases of carcinoma of the thyroid.
10-929	"Iodotope" Oral Solution and Caps	5/2/57	Squibb	Diagnosis of thyroid function, for thyroid imaging. To localize metastases associated with thyroid malignancies. Treatment of hyperthyroidism and selected cases of carcinoma of the thyroid.
16-515	Sodium Iodide I 131 Oral Solution	8/18/71	Mallinckrodt	Diagnosis of thyroid function, for thyroid imaging. To localize metastases associated with thyroid malignancies. Treatment of hyperthyroidism and selected cases of carcinoma of the thyroid.

APPENDIX V-A (cont'd)

ABBREVIATED SUMMARY OF APPROVED RADIOPHARMACEUTICAL DRUG PRODUCTS

NDA	Trade Name	Date Orig. Approved	Firm	Indication
16-517	Sodium Iodide I 131 Capsules	8/20/71	Mallinckrodt	Diagnosis of thyroid function, for thyroid imaging. To localize metastases associated with thyroid malignancies. Treatment of hyperthyroidism and selected cases of carcinoma of the thyroid.
Sodium Iodide I 131 (cont'd)				
17-316	Sodium Iodide I 131 Capsules	11/9/76	CIS	Diagnosis of thyroid function, for thyroid imaging. To localize metastases associated with thyroid malignancies.
17-315	Sodium Iodide I 131 Solution	11/16/76	CIS	Treatment of hyperthyroidism and selected cases of carcinoma of the thyroid.
Iodohippurate Sodium I 131 Injection				
16-274	"Hippuran-131"	3/20/68	Abbott	Diagnostic aid in determining renal function, renal blood flow and urinary tract obstruction.
16-666	"Hippuran-131" I-131 Inj.	5/24/68	Mallinckrodt	Diagnostic aid in determining renal function, renal blood flow and urinary tract obstruction.
15-419	"Hipputope"	6/25/70	Squibb	Diagnostic aid in determining renal function, renal blood flow and urinary tract obstruction.
17-313	Iodohippurate Sodium I 131 Injection	11/16/76	CIS	Diagnostic aid in determining renal function, renal blood flow and urinary tract obstruction.

APPENDIX V-A (cont'd)

ABBREVIATED SUMMARY OF APPROVED RADIOPHARMACEUTICAL DRUG PRODUCTS

NDA	Trade Name	Date Orig. Approved	Firm	Indication
		Iothalamate Sodium I 125 Injection		
17-279	"Glofil-125"	2/12/74	Abbott	Evaluation of glomerular filtration in the diagnosis or monitoring of patients with renal disease.
		Sodium Phosphate P 32		
8-447	Sodium Phosphate P 32 Oral Solution, Injection	6/30/52	Abbott	Treatment of polycythemia vera, treatment of chronic myelocytic leukemia and chronic lymphocytic leukemia. Diagnostic aid in localizing certain occular tumors; cerebral tumors at time of surgery in conjunction with a surgical radiation detection probe (only when other techniques are unsuitable for this purpose).
10-927	"Phosphotope" Oral Solution, Injection	5/2/57	Squibb	Treatment of polycythemia vera, treatment of chronic myelocytic leukemia and chronic lymphocytic leukemia. Diagnostic aid in localizing certain occular tumors, cerebral tumors at time of surgery in conjunction with a surgical radiation detection probe.
11-777	Sodium Phosphate P 32 Injection, Capsules	3/4/59	Mallinckrodt	Treatment of polycythemia vera, treatment of chronic myelocytic leukemia and chronic lymphocytic leukemia. Diagnostic aid in localizing certain occular tumors, cerebral tumors at time of surgery in conjunction with a surgical radiation detection probe.
		Sodium Rose Bengal I 131 Injection		
16-224	"Robengatope"	11/23/71	Squibb	Diagnostic aid for determination of liver function and liver imaging.

APPENDIX V-A (cont'd)

ABBREVIATED SUMMARY OF APPROVED RADIOPHARMACEUTICAL DRUG PRODUCTS

NDA	Trade Name	Date Orig. Approved	Firm	Indication
Sodium Rose Bengal I 131 Injection				
16-665	Sodium Rose Bengal I 131 Injection	2/11/74	Mallinckrodt	Diagnostic aid for determination of liver function and liver imaging.
17-318	Sodium Rose Bengal I 131 Injection	11/16/76	CIS	Diagnostic aid for determinatin of liver function and liver imaging.
Strontium Sr 87m				
17-445	Strontium 87m Generator	3/25/74	Amersham	Bone imaging agent.
Strontium Nitrate Sr 85 Injection				
17-024	"Strotope"	7/10/73	Squibb	Bone imaging agent.
17-260	"Stronscan-85"	12/17/73	Abbott	Bone imaging agent.
Technetium Tc 99m Pentetate Sodium Kit (Formerly Known as DTPA) (diethylenetriamine pentaacetic acid)				
17-045	"Renotec" Tc 99m Iron-Ascorbate-DTPA Kit	7/8/74	Squibb	Kidney imaging agent.
17-264	Technetium 99m DTPA Kit	2/14/74	Union Carbide	Kidney and brain imaging, assess renal perfusion, estimate glomerular filtration.
17-255	Technetium 99m DTPA Kit	4/15/76	Diagnostic Isotopes	Kidney and brain imaging, assess renal perfusion, estimate glomerular filtration.

APPENDIX V-A (cont'd)

ABBREVIATED SUMMARY OF APPROVED RADIOPHARMACEUTICAL DRUG PRODUCTS

NDA	Trade Name	Date Orig. Approved	Firm	Indication
		Technetium Tc 99m Penetate Soduim Kit (Formerly Known as DTPA) (diethylenetriamine pentaacetic acid) (cont'd)		
17-626	Technetium Tc 99m DTPA Kit	11/19/76	General Radioisotope Products	Kidney and brain imaging, assess renal perfusion,estimate glomerular filtration.
17-714	Technetium Tc 99m DTPA Kit	11/16/76	CIS	Kidney and brain imaging, assess renal perfusion, estimate glomercular filtration.
		Technetium Tc 99m Etidronate Sodium Kit		
17-454	"Osteoscan"	9/28/73	Procter & Gamble	Skeletal imaging agent used to demonstrate areas of altered osteogenesis and a cardiac imaging agent used as an adjunct in the diagnosis of acute myocardial infarction.
17-562	Technetium Tc 99m Diphosphonate-Tin Kit	8/5/76	Diagnostic Isotopes	Bone imaging agent used to delineate areas of altered osteogenesis.
17-653	"Hedspa" (Technetium Tc 99m Etidronate Kit)	11/18/76	Union Carbide	Skeletal imaging agent used to delineate areas of altered osteogenesis.
17-667	MPI Stannous Diphosphonate	4/1/77	Medi-Physics	Bone imaging agent used to delineate areas of altered osteogenesis.
		Technetium Tc 99m Generator		
17-243	"Ultra-TechneKow"	11/23/73	Mallinckrodt	Brain, thyroid and salivary gland imaging; placenta localization and blood pool imaging.

APPENDIX V-A (cont'd)

ABBREVIATED SUMMARY OF APPROVED RADIOPHARMACEUTICAL DRUG PRODUCTS

NDA	Trade Name	Date Orig. Approved	Firm	Indication
Technetium Tc 99m Generator				
17-243 S-001	"Elutek"	11/23/76	Distribution by Abbott	Brain, thyroid and salivary gland imaging; placenta localization and blood pool imaging.
17-339	"Minitec" (Technetope Hi Conc Sterile Generator)	6/3/74	Squibb	Brain, thyroid and salivary gland imaging; placenta localization and blood pool imaging.
17-470	"Mektec 99"	6/10/74	Imaj International	Brain, thyroid and salivary gland imaging; placenta localization and blood pool imaging.
17-281	Technetium Tc 99m Generator	8/30/74	New England Nuclear	Brain, thyroid and salivary gland imaging; placenta localization and blood pool imaging.
16-906	"Technetope" II	9/20/74	Squibb	Brain, thyroid and salivary gland imaging; placenta localization and blood pool imaging.
17-249	Technetium Tc 99m Generator	11/16/76	General Radioisotopes Products	Brain, thyroid and salivary gland imaging; placenta localization and blood pool imaging.
17-693	Technetium Tc 99m Generator	11/15/76	Unionc Carbide	Brain, thyroid and salivary gland imaging; placenta localization and blood pool imaging.
17-693 S-004	"ScintiCheck"	11/15/76	Distribution by Searle	Brain, thyroid and salivary gland imaging; placenta localization and blood pool imaging.
17-771	Technetium Tc 99m Generator (Fission)	11/16/76	New England Nuclear	Brain, thyroid and salivary gland imaging; placenta localization and blood pool imaging.

APPENDIX V-A (cont'd)

ABBREVIATED SUMMARY OF APPROVED RADIOPHARMACEUTICAL DRUG PRODUCTS

NDA	Trade Name	Date Orig. Approved	Firm	Indication
		Sodium Pertechnetate Tc 99m Solution		
17-267	Sodium Pertechnetate Tc 99m	10/2/73	Union Carbide	Brain, thyroid and salivary gland imaging; placenta localization and blood pool imaging.
17-121	Sodium Pertechnetate Tc 99m	4/30/74	Mallinckrodt	Brain, thyroid and salivary gland imaging; placenta localization and blood pool imaging.
16-825	"Pertscan-99m" Tc 99m	5/14/74	Abbott	Brain, thyroid and salivary gland imaging; placenta localization and blood pool imaging.
17-471	Sodium Pertechnetate Tc 99m	7/18/74	Medi-Physics	Brain, thyroid and salivary gland imaging; placenta localization and blood pool imaging.
17-321	Sodium Pertechnetate Tc 99m	10/20/76	CIS	Brain, thyroid and salivary gland imaging; placenta localization and blood pool imaging.
17-764	Sodium Pertechnetate Tc 99m	11/16/76	New England Nuclear	Brain, thyroid and salivary gland imaging; placenta localization and blood pool imaging.
17-725	Sodium Pertechnetate Tc 99m	12/30/77	Gamma Diagnostics	Brain, thyroid and salivary gland imaging; placenta localization and blood pool imaging.

APPENDIX V-A (cont'd)

ABBREVIATED SUMMARY OF APPROVED RADIOPHARMACEUTICAL DRUG PRODUCTS

NDA	Trade Name	Date Orig. Approved	Firm	Indication
		Technetium Tc 99m Medronate Sodium Kit (Formerly Known as MDP)		
17-972	"Osteolite"	12/16/77	New England Nuclear	May be used as a bone imaging agent to delineate areas of altered osteogenesis.
		Technetium Tc 99m Gluceptate Sodium Kit		
17-907	"Glucoscan"	5/25/78	New England Nuclear	Used for brain imaging. Indicated for renal perfusion imaging as an adjunct in the diagnosis, localization and evaluation of kidney disease.
		Technetium Tc 99m Sodium Pyrophosphate/ Polyphosphate Kit		
17-538	"TechneScan PYP" Kit	5/28/74	Mallinckrodt	Skeletal imaging agent used to demonstrate areas of altered osteogenesis and a cardiac imaging agent used as an adjunct in the diagnosis of acute myocardial infarction.
17-680	"Phosphotec"	10/20/76	Squibb	Bone imaging agent used to delineate areas of altered osteogenesis and a cardiac imaging agent used as an adjunct in the diagnosis of acute myocardial infarction.
17-664	Technetium Tc 99m Polyphosphate Kit	10/27/76	Diagnostic Isotopes	Bone imaging agent used to delineate areas of altered osteogenesis.
17-684	"Pyrolite"	11/19/76	New England Nuclear	Bone imaging agent used to delineate areas of altered osteogenesis.
17-678	Technetium Tc 99m Polyphosphate Tin Kit	7/29/77	General Radioisotope Products	Bone imaging agent used to delineate areas of altered osteogenesis.

ABBREVIATED SUMMARY OF APPROVED RADIOPHARMACEUTICAL DRUG PRODUCTS

Technetium Tc 99m Sulfur Colloid Injection and Kit

NDA	Trade Name	Date Orig. Approved	Firm	Indication
17-026	Tc 99m Sulfur Colloid Injection	3/11/74	Mallinckrodt	Imaging agent for functioning of reticulo-endothelial cells in the liver, spleen and bone marrow.
17-266	Tc 99m Sulfur Colloid Injection	4/10/74	Union Carbide	Imaging agent for functioning of reticulo-endothelial cells in the liver, spleen and bone marrow.
16-923	"Tesuloid" (Sulfur Colloid Kit)	6/10/74	Squibb	Imaging agent for functioning of reticulo-endothelial cells in the liver, spleen and bone marrow.
17-282	Tc 99m Sulfur Colloid Kit	8/22/74	New England Nuclear	Imaging agent for functioning of reticulo-endothelial cells in the liver, spleen and bone marrow.
17-456	Tc 99m Sulfur Colloid Injection	9/24/74	Medi-Physics Inc.	Imaging agent for functioning of reticulo-endothelial cells in the liver, spleen and bone marrow.
17-059	"TechneColl" (Sulfur Colloid Kit)	9/30/74	Mallinckrodt	Imaging agent for functioning of reticulo-endothelial cells in the liver, spleen and bone marrow.
17-059 S-001	"ColloKit"	12/10/74	Distribution by Abbott	Imaging agent for functioning of reticulo-endothelial cells in the liver, spleen and bone marrow.
17-317	Technetium Tc 99m Sulfur Colloid Injection	11/18/76	CIS	Imaging agent for functioning of reticulo-endothelial cells in the liver, spleen and bone marrow.

APPENDIX V-A (cont'd)

ABBREVIATED SUMMARY OF APPROVED RADIOPHARMACEUTICAL DRUG PRODUCTS

NDA	Trade Name	Date Orig. Approved	Firm	Indication
		Technetium Tc 99m Sulfur Colloid Injection and Kit (cont'd)		
17-784	Technetium Tc 99m Suflur Colloid Kit	11/18/76	Union Carbide	Imaging agent for functioning of reticulo-endothelial cells in the liver, spleen and bone marrow.
17-858	Technetium Tc 99m Sulfur Colloid Kit	4/17/78	CIS	Imaging agent for functioning of reticulo-endothelial cells in the liver, spleen and bone marrow.
17-724	Technetium Tc 99m Sulfur Colloid Injection	8/18/78	Gamma Diagnostics	Imaging agent for functioning of reticulo-endothelial cells in the liver, spleen and bone marrow.
		Thallous Chloride Tl 201		
17-806	Thallous Chloride Tl 201	12/16/77	New England Nuclear	May be useful in myocardial perfusion imaging for the diagnosis and localization of myocardial infarction.
		Triolein (glyceryl Trioleate) I 131		
7-216	Triolein I 131 Capsules	7/18/73	Mallinckrodt	Agent to estimate fat absorption.
17-217	Triolein I 131 Solution	7/19/73	Mallinckrodt	Agent to estimate fat absorption.
		Xenon Xe 133		
17-262	"Xeneisol" Xe 133 Injection (Solution)	7/11/73	Mallinckrodt	Diagnosis of cardiac abnormalities, cerebral blood flow studies, pulmonary function studies and muscle blood flow studies.

APPENDIX V-A (cont'd)

ABBREVIATED SUMMARY OF APPROVED RADIOPHARMACEUTICAL DRUG PRODUCTS

Xenon Xe 133 (cont'd)

NDA	Trade Name	Date Orig. Approved	Firm	Indication
17-283	Xenon Xe 133 Injection (Solution)	10/11/74	New England Nuclear	Diagnosis of cardiac abnormalities, cerebral blood flow studies, pulmonary function studies and muscle blood flow studies.
17-284	Xe 133 Gas	10/10/74	New England Nuclear	Evaluation of pulmonary function, imaging of lungs, assessment of cerebral flow.
17-550	Xenon Xe 133 Gas	3/24/76	General Electric	The gas may be used for inhalation studies in the evaluation of pulmonary function, for imaging the lungs, or the assessment of cerebral blood flow. The solution may be used for the diagnosis of cardiac abnormalities; cerebral blood flow, pulmonary function or muscle blood flow studies.
17-256	Xenon Xe 133 Gas or Solution	11/9/76	Diagnostic Isotopes	The gas may be used for inhalation studies in the evaluation of pulmonary function, for imaging the lungs, or the assessment of cerebral blood flow. The solution may be used for the diagnosis of cardiac abnormalities; cerebral blood flow, pulmonary function or muscle blood flow studies.
17-687	Xenon Xe 133-V.S.S. (Ventillation Study System)	11/16/76	Medi-Physics	Study of pulmonary ventilation.

APPENDIX V-A (cont'd)

ABBREVIATED SUMMARY OF APPROVED RADIOPHARMACEUTICAL DRUG PRODUCTS

NDA	Trade Name	Date Orig. Approved	Firm	Indication
		Ytterbium Yb 169 Pentetate Sodium (Formerly Known as DTPA)		
17-518	Ytterbium Yb 169 DTPA	3/11/76	Nuclear Products 3 M Co.	Diagnostic use in radionuclide cisternography.

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* Individual chose to remain anonymous.

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